Characterizing Motion Control Systems to Enable Accurate Continuous and Event-Based Scans

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INTRODUCTION

The European Spallation Source (ESS) is a collaborative project developing the world's strongest neutron source for insights into materials' structures and dynamics in fields such as physics, biology, and archaeology. Using event mode data handling, the ESS records each neutron's timestamp and pixel identifier for detailed analysis [1, 2]. The ESS timing system ensures precise timestamping and synchronization across subsystems [3]. This study assesses the uncertainty in the position of a linear stage based on an event's timestamp to evaluate the performance of ESS motion control systems in continuous and event-based scans.

METHOD

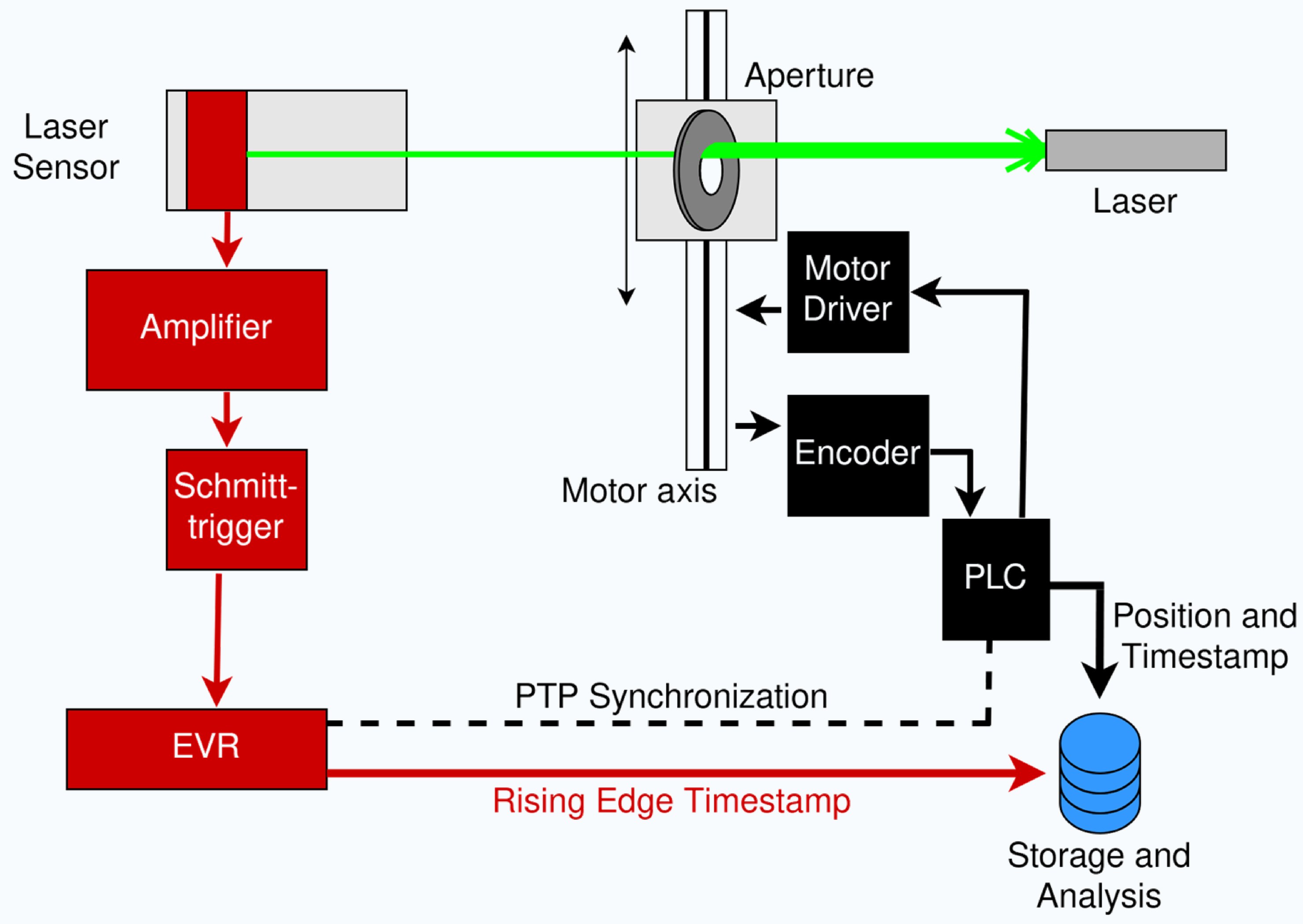

Figure 1: The setup consists of two subsystems that acquire timestamped data independently. The laser subsystem (red) consists of a laser sensor that is connected to an Event Receiver (EVR), which timestamps rising edge events. The motor subsystem (black) consists of the PLC that controls the motor, reads the encoder position, and timestamps the encoder position. The PLC is time synchronised using Precision Time Protocol (PTP) to the same clock as the EVR.

The experiment setup includes a linear stage with a motor and encoder as well as a laser-based position detection system that emits a 5V TTL pulse for timestamping in an event receiver (EVR). A Beckhoff PLC controls the linear stage, allowing control based on encoder readings. The documented specifications for the linear stage accuracy is ±20 µm, and repeatability is ±3 µm.

Data is recorded every 10 ms, synchronized through the facility's timing system. Improved timing synchronization accuracy using PTP enhances the repeatability of the linear stage. During scans, motor movements across the laser path are recorded, with event timestamps compared with encoder data for inferred motor positions at event times.

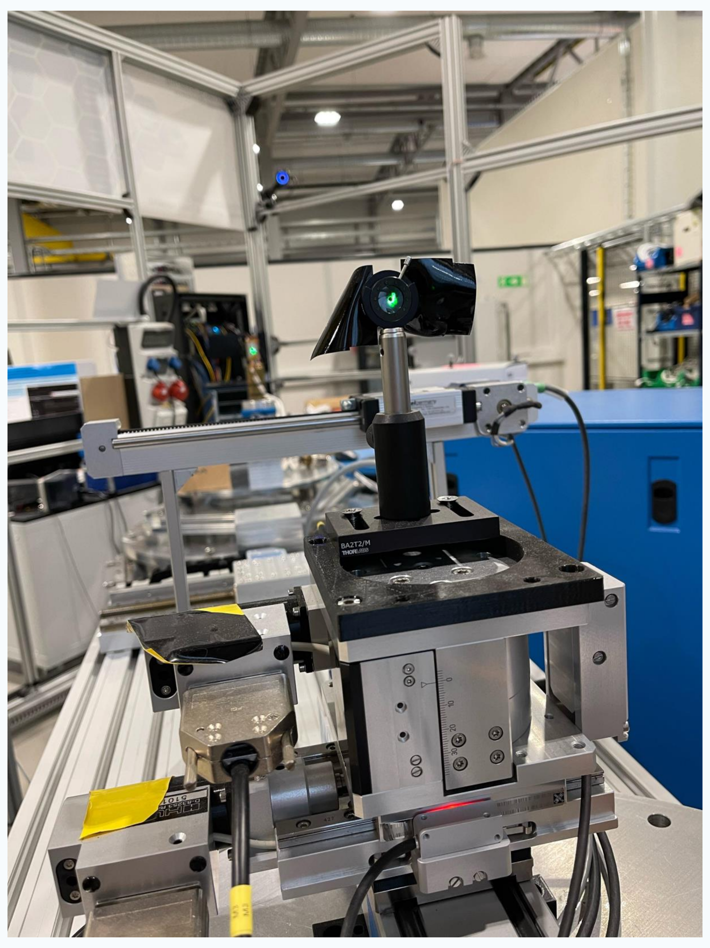

Figure 2: Photo of the laser shining on the aperture. The aperture is mounted on a three-axis linear stage platform where only the horizontal linear stage is scanned.

RESULTS

Motor positions interpolated using EVR timestamps and motor timestamps are collected over 23 hours, with approximately 400 valid events per motor speed. Figure 4 shows that the position quartile width increases with increasing motor speeds. Despite these variations, the trigger location's average remains constant, with symmetric quartile spreads around the mean. The observed spread in position, ranging from 14µm to 25µm, closely approaches the linear stage's limits.

Since the system only exhibits speed-dependent spread and no shift of the mean, it is likely governed by mechanical uncertainties, vibrations and timing jitter rather than constant latencies in the timestamping process. The measured jitter from the laser sensor is, at worst, ±10 µs, and the synchronization jitter in the PLC is below 1 µs. With the motor running at a max speed of 5 mm/s, the positional inaccuracies due to this timing jitter can be disregarded because it is well below the ±3 µm repeatability of the linear stage. This also indicates that the system is limited by mechanical factors rather than timing.

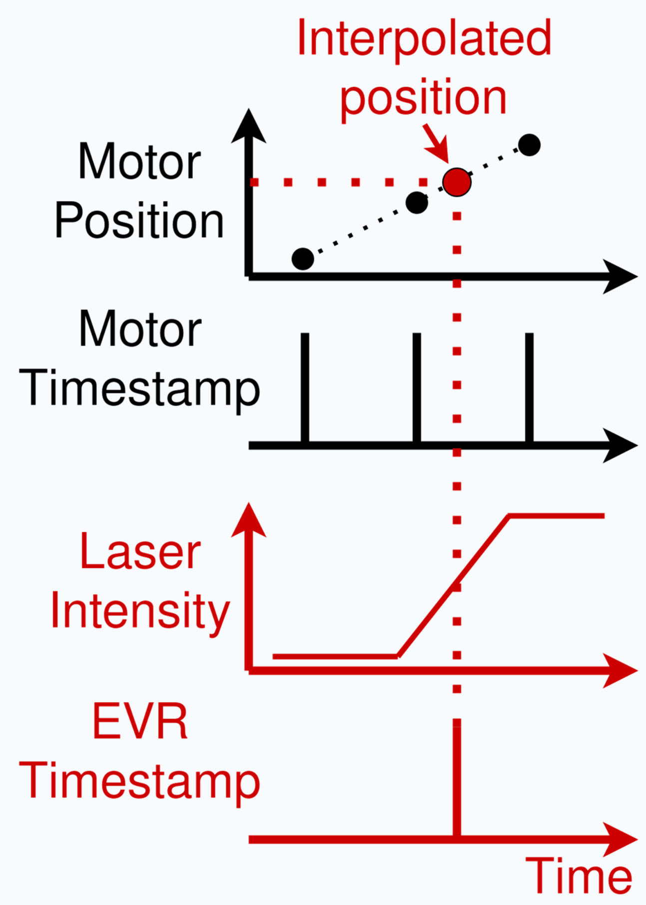

Figure 3: When the laser intensity crosses a threshold, a rising edge is sent to the EVR for timestamping (red graphs). The assumed motor position at this point in time is interpolated from the encoder positions reported at fixed intervals (black graphs).

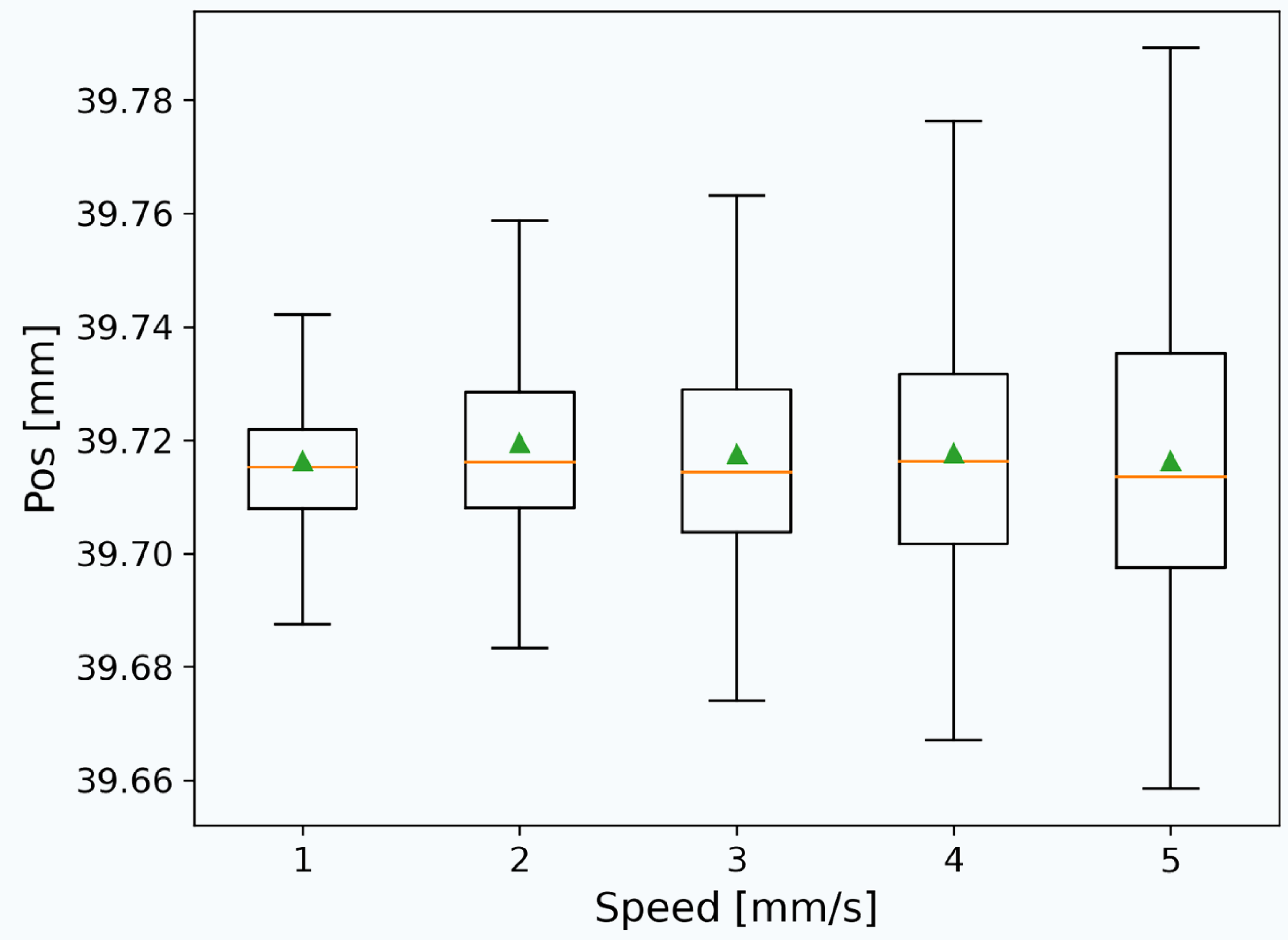

Figure 4: The interpolated motor positions are shown as a boxplot for each motor speed. The box shows the lower and upper quartiles, the line represents the median, and the mean is the triangle.

DISCUSSION AND OUTLOOK

This study characterizes the motor accuracy in the instrument control system, noting a standard deviation of 25 micrometres in interpolated motor position under specific conditions. Time uncertainties were minor compared to mechanical effects, with a linear relationship between the standard deviation of interpolated motor position and motor speed; the speed-independent mean position also indicates negligible latency in the timestamping process. These insights are crucial for instrument teams planning experiments as they provide clarity on the system's limitations and capabilities.

Moreover, these findings serve as a benchmark for assessing the system's performance following upgrades or modifications, facilitating the tracking of the impact of incremental changes to software or hardware on the system's performance.

An automated test rig is in development to evaluate software updates before deployment, aiding in this comparative assessment. Additionally, there is a planned upgrade to incorporate a higher bandwidth laser sensor to enhance time resolution.

EUROPEAN SPALLATION SOURCE

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