

Towards Standardized Benchmarking of SGRT Technologies: Development and Validation of a Mechatronic Phantom for Quantitative Tracking-Performance QA

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Purpose

Table 4 of the ESTRO-ACROP guideline requires *tracking performance* (D2) to be verified at 1 mm / 1°, monthly to annually on a C-arm linac.[1] It defines what must be tested and to what tolerance — but not how the number is produced: no reference hardware or motion pattern. Our institution features four linac systems equipped with the ExacTrac Dynamic (ETD) system.

Materials and Methods

We built a mechatronic phantom from open, off-the-shelf parts: 20 × 20 mm aluminum profiles, 3D-printed PLA parts, closed-loop CNC steppers moving two spindle-driven axes resolving 1.25 µm per step. Two axes are kinematically coupled, so every vertical move carries pitch, which also lets the phantom simulate a respiratory trace. Phantom and tracking system log on independent, free-running clocks. Sync pulses bracketing each run recover the start offset and clock rate; a fixed measurement window then selects which samples are used to compute the metrics. A steel sphere at the phantom centre ties the mechanical frame to the radiographic isocentre.

Results

Three repeat runs across all axes (± 10 mm / $\pm 5^\circ$) were aligned separately and compared against the calibrated kinematic model. RMSE reached 0.273 mm for translations and 0.105° for rotations. Sphere detection reproduced a commanded 10 mm shift to 0.0 mm on the longitudinal axis and revealed a 1.1 mm offset of the sphere from the rotation axis. It also calibrated the vertical-axis kinematics across all linac systems.

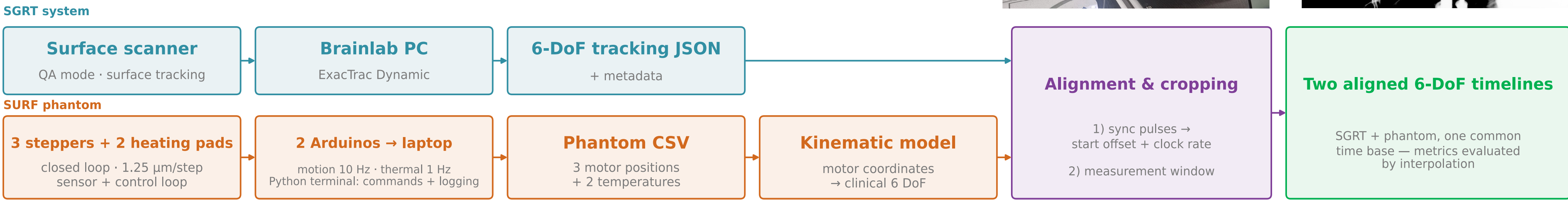


Figure 1: Standard QA compares tracking data against the phantom ground truth, producing a final dataset for QA and other analyses.

Abbreviations: Degree of Freedom – DoF, Root mean square error – RMSE, sphere detection – SD; **References:** [1] Freisleder P, et al.: ESTRO-ACROP guideline on surface guided radiation therapy. *Radiotherapy and Oncology*, 2022; 173:188-196

Conclusion

A phantom built from open components makes tracking performance measurable rather than estimated, provided the path from motion to metric is specified as carefully as the hardware. Next: a breast-surface phantom on the same platform, and a gated versus ungated EPID comparison. For **more pictures, complete comparison of tracking data** and our code with automated report creation, scan the **QR code**.

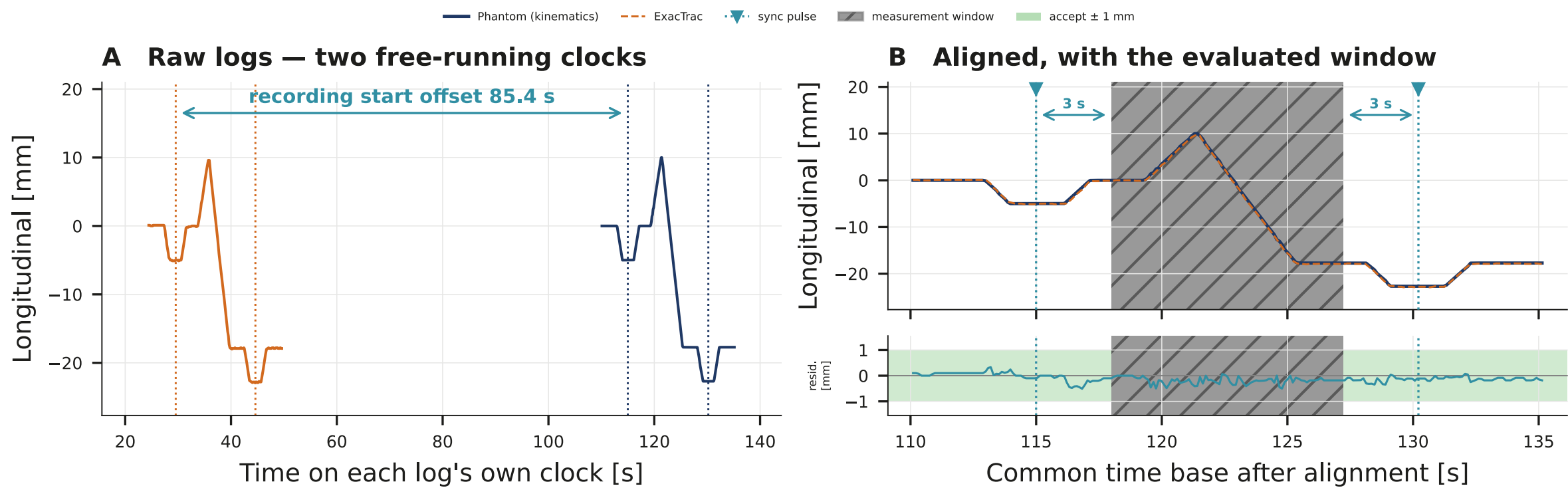


Figure 3 & 4 to the left: Our phantom on the treatment couch (left) & X-ray image of phantom by the ETD SD tool

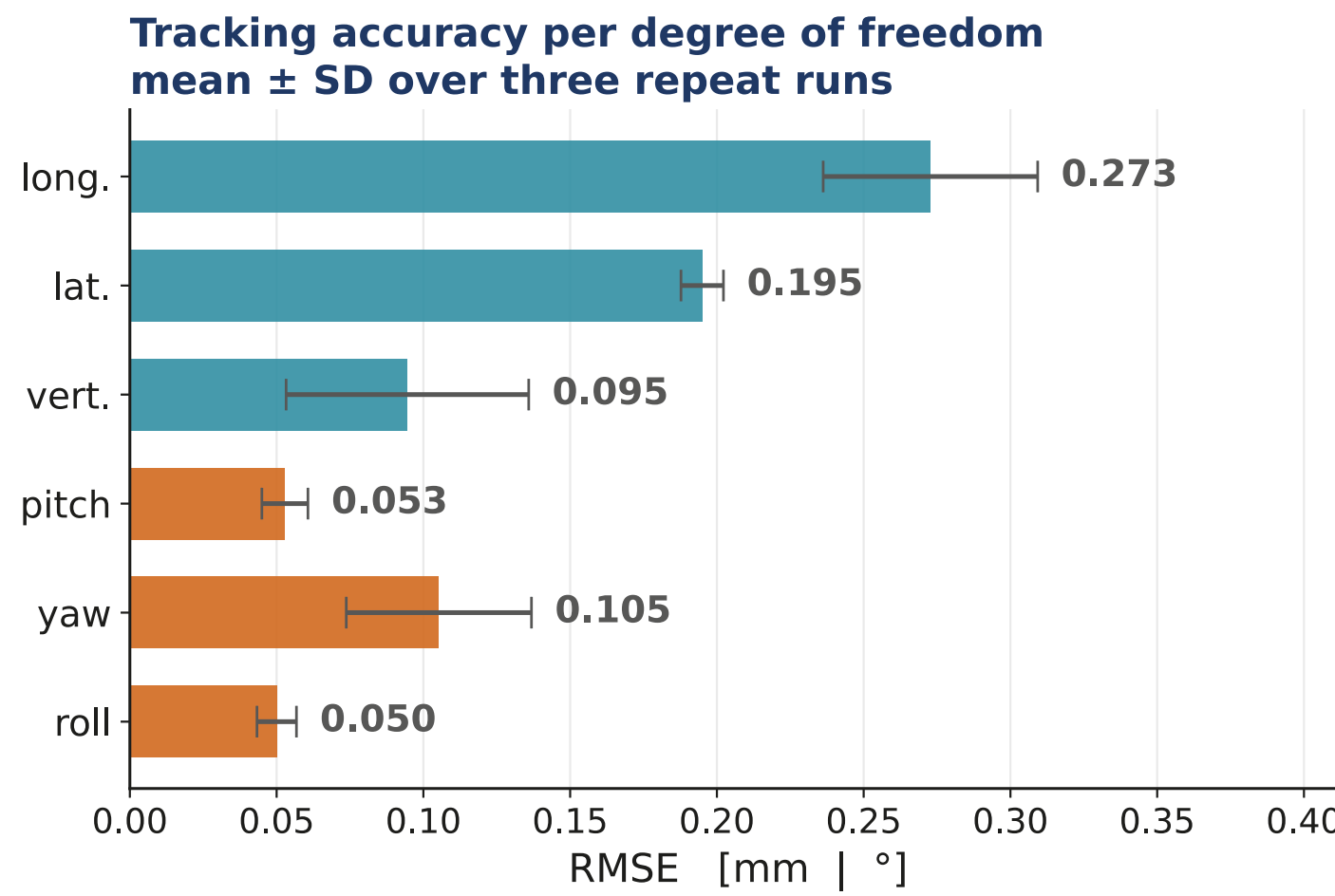


Figure 5: For each of the three runs and its DoFs the RMSE, mean and standard deviation are shown.