Hybrid Respiratory Motion Tracking Using X-Ray Imaging and Integrated Infrared Cameras In a Mobile CBCT System

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ABSTRACT

To assess the agreement in motion tracking at a mobile cone-beam computed tomography (CBCT) X-ray imaging system integrating optical cameras, at varying gantry angle and breathing motion complexity.

A metal marker was attached to the moving rod in the CIRS dynamic motion phantom, with a $\cos^4$ respiratory motion trace and breathing periods set to 2.55, 3, 4, and 5 s. Eight CBCT datasets were acquired at 80 kVp and 11.9 frames per second for a total duration of 60 s with full 360° gantry rotation using two filtering windows for the optical cameras (OptiTrack): 700 ms, to generate smoother motion trajectories, and 80 ms, to capture higher temporal resolution. A quantitative evaluation was performed using the root mean square error (RMSE) with respect to the nominal motion trace. An image-enhanced template-matching (TM) algorithm was used to track the centroid of the metal marker in CBCT projection images. Performance was also evaluated using the **high-motion, high-complexity** cases from the AAPM Markerless Lung Target Tracking (MATCH) dataset to determine the influence of the filtering window under challenging respiratory motion conditions.

Marker trajectories derived from CBCT projections demonstrated maximum deviations of 0.76 mm, in good agreement with the accuracy of the optical tracking system (0.81 mm). The X-ray source rotation in CBCT acquisition introduced a sinusoidal component in the TM-derived motion signal, which was corrected by detecting the plateau regions in the $\cos^4$ breathing trace. The 80 ms filtering window resulted in reduced mismatch between tracked and reference trajectories for the optical cameras for faster respiratory motion. Overall sub-millimetre tracking accuracy was achieved using the challenging irregular respiratory motion datasets.

Mobile CBCT with integrated OptiTrack enables tumour motion tracking with accuracy comparable to ground truth under realistic breathing conditions.

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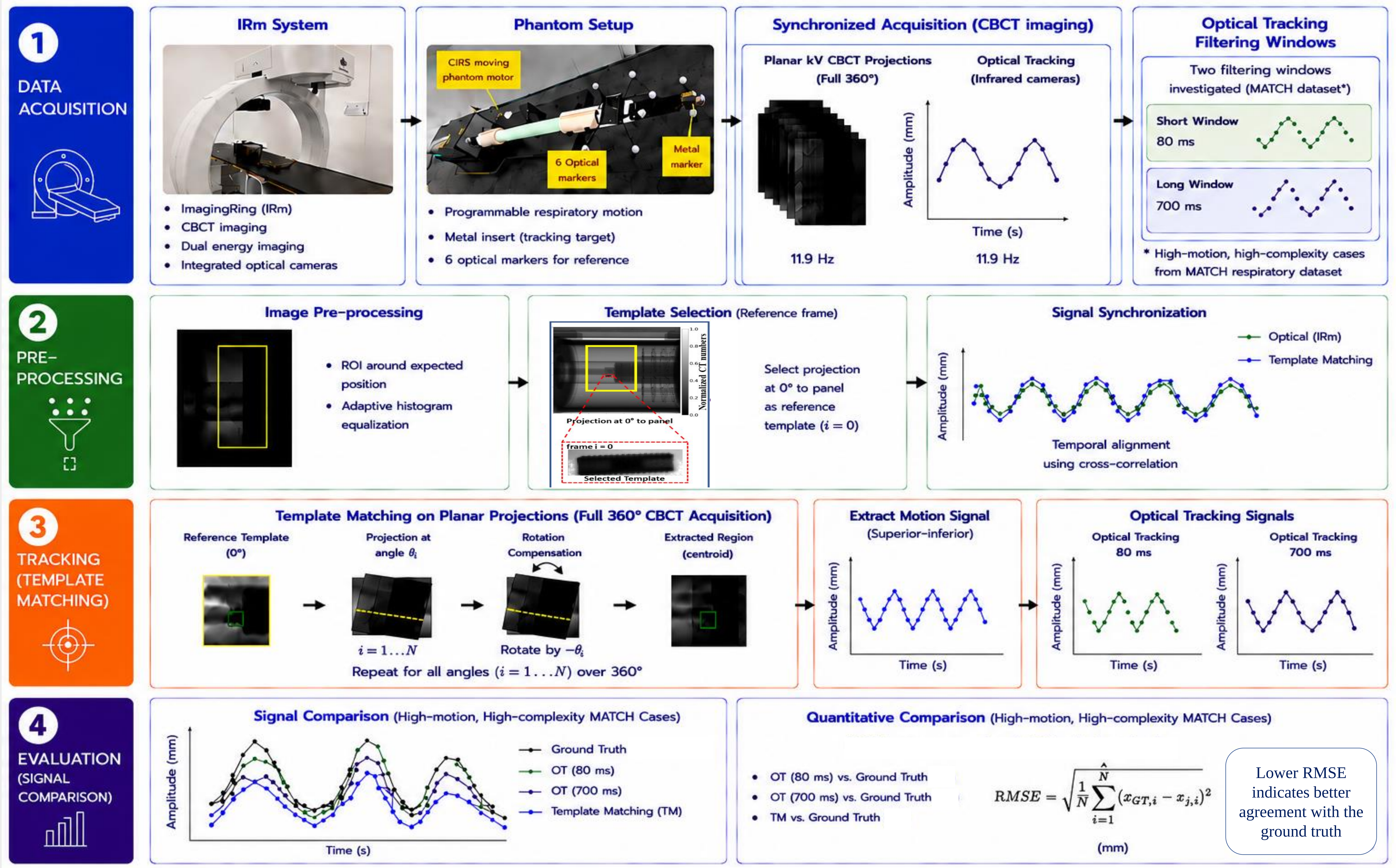


OUTCOME: Determine the impact of Optical Tracking filtering windows (80 ms vs 700 ms) vs the template matching performance for the metal tracking vs the ground truth in a moving phantom using CBCT imaging

RESULTS

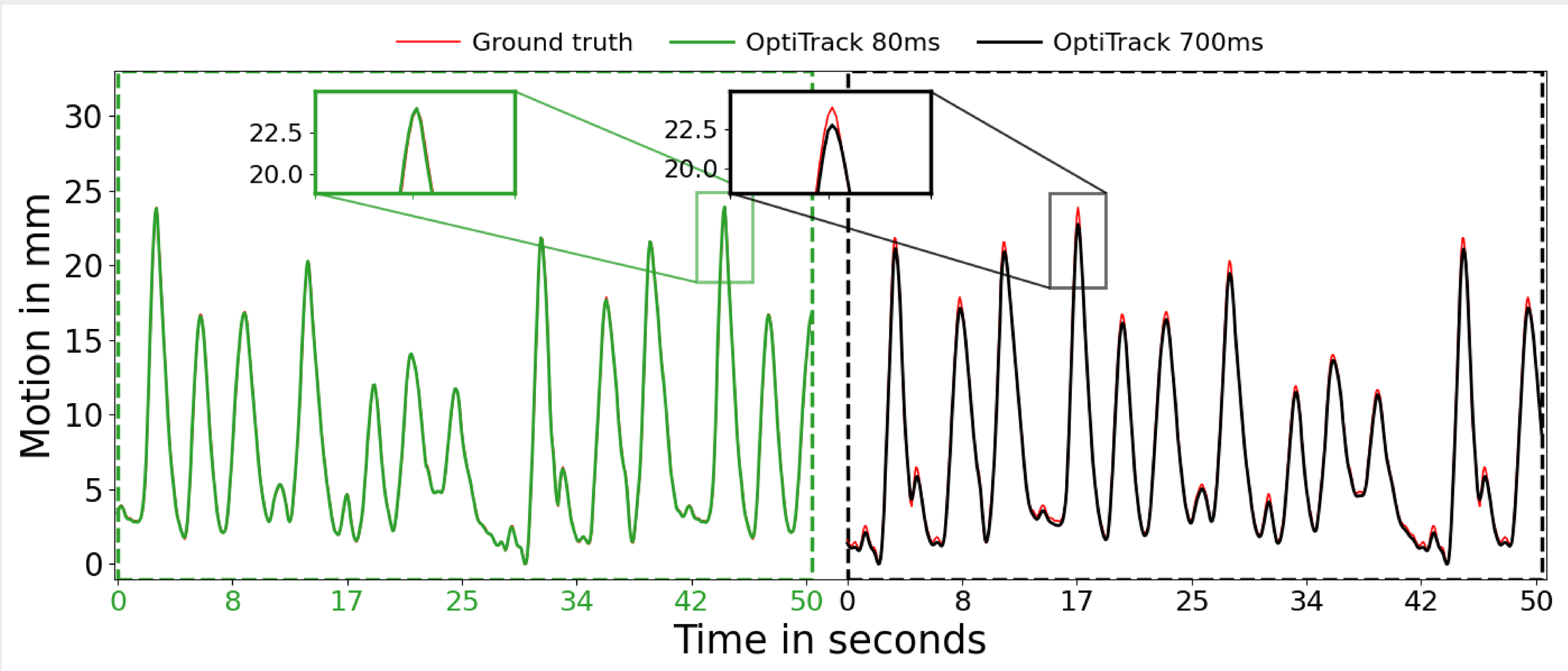
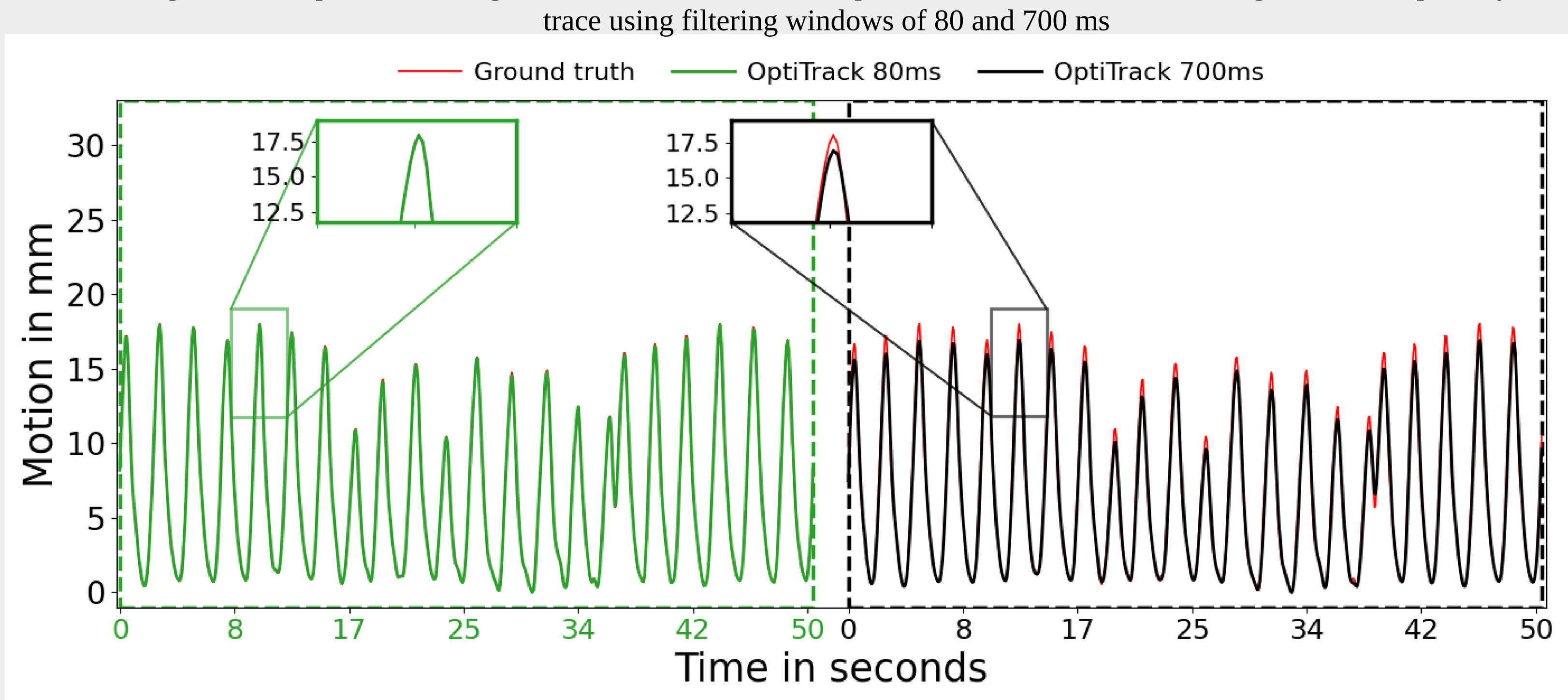


Figure 1: Comparison of the ground truth motion and the OptiTrack measurements for the high complexity respiratory trace using filtering windows of 80 and 700 ms

Figure 2: Comparison of the ground truth motion and the OptiTrack measurements for the high motion respiratory trace using filtering windows of 80 and 700 ms



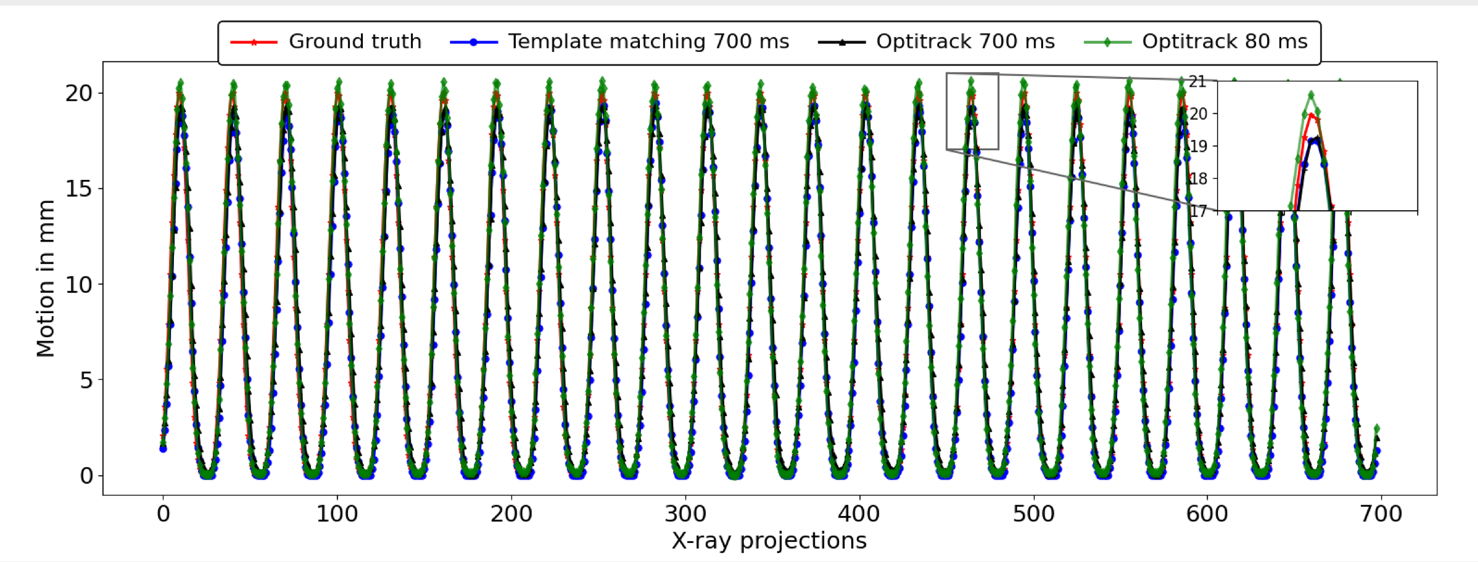


Figure 3: Motion measured in X-ray projections using template matching and external optical tracking cameras vs. the GT, for 80ms and 700ms filtering window in the 2.55 s breathing period.

Table 1. RMSE [mm] comparison between OptiTrack (OT) cameras signal and ground truth (MATCH).

Studies	80ms	700ms
High complexity	0.234	0.355
High motion	0.153	0.576

Table 2. RMSE [mm] comparison between OptiTrack (OT) cameras signal and template matching.

Breathing period	2.55 s	3 s	4 s	5 s
OT 80ms	0.7	0.54	0.39	0.57
OT 700ms	0.81	0.99	0.37	0.33
Template matching	0.76	0.61	0.5	0.58

CONCLUSIONS: The optical tracking camera and IRm system offers submillimeter accuracy but shorter OptiTrack filtering window highlights the importance of temporal resolution for motion estimation, motion compensation, and respiratory-resolved CBCT techniques for image-guided radiotherapy.

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