RESIDENT-FOCUSED LAPAROSCOPIC TOOL TRACKER: AUTOMATED OFF-AXIS PERFORMANCE ANALYTICS ALIGNED WITH OSATS AND GOALS

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Background/Introduction

Surgical resident laparoscopic training has increasingly been tied to objective measures of proficiency using tools such as the OSATS scoring system [1]. Surgical proficiency has also previously been tied to measures such as time to task completion and semi-objective measures of task competency based on the specific training exercise [2]. With the advent of new optical processing algorithms becoming widely available, the time is right to create a training device which can automatically evaluate efficiency metrics and enable clinicians to better use their time teaching trainees rather than reviewing training video.

Purpose/Objectives/Hypothesis

To deliver a resident-training tool that supports intentional practice under off-axis viewing conditions and generates objective, de-identified performance metrics enabling:

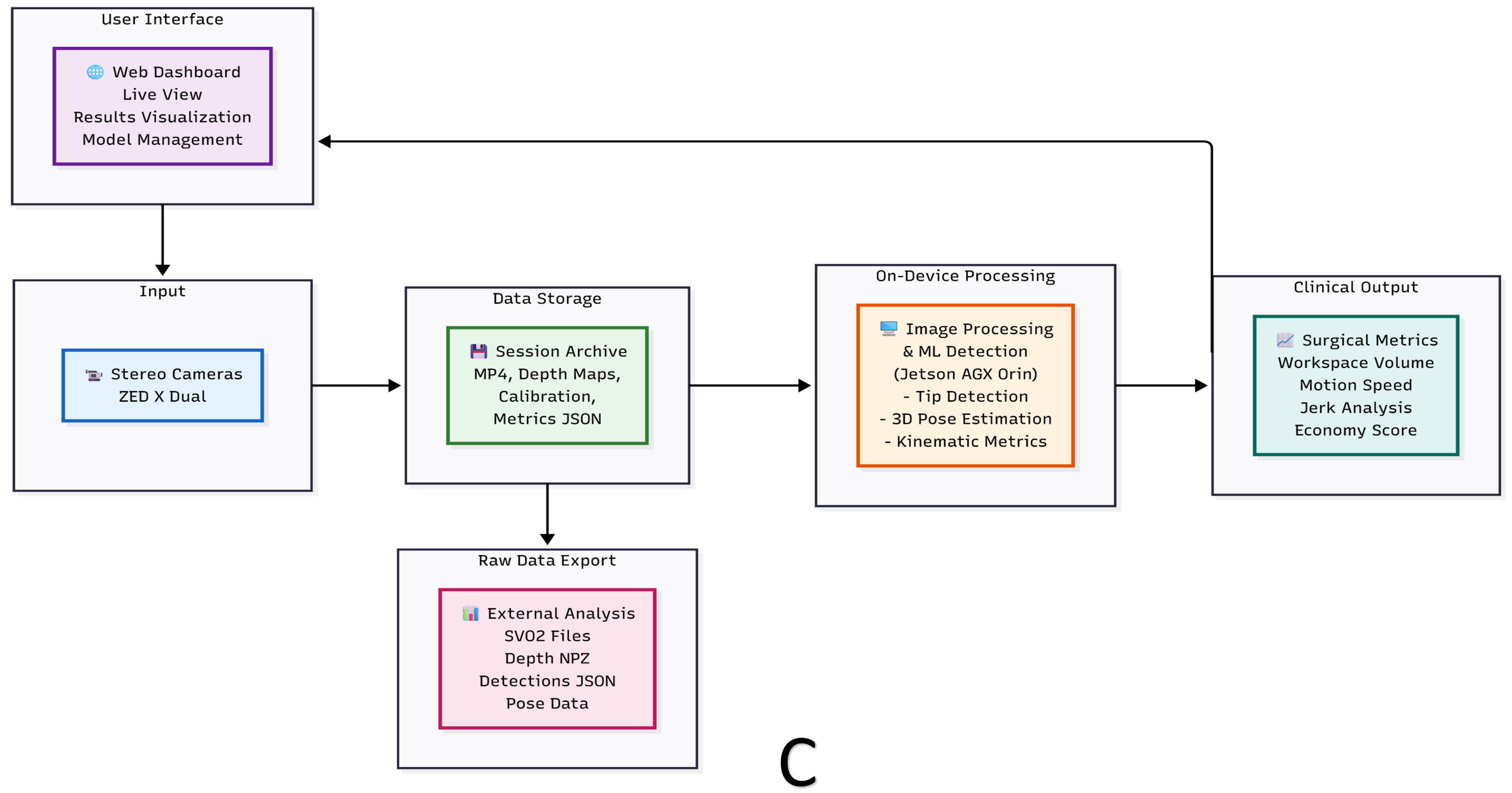
- Targeted feedback
- Learner stratification
- Reduced faculty scoring burden

Methods

The software first calibrates the dual binocular ZED camera system using a ChArUco board and captures >5 frames at varied positions including tilted views for the extrinsic and stereo calibrations. Intrinsic calibration of the ZED camera is NOT re-calibrated and is read from the factory calibration. Instruments used during testing were Maryland forceps tagged with green and pink bands for L/R differentiation and a peg transfer task board. Next, the instrument is segmented using the SAM2 ML model to create a base instrument image mask for validation and orientation analysis [3]. SAM2 struggles with full occlusion and cannot identify the instrument tip. For this purpose, CoTracker3 is used to identify the instrument tip based on a manually placed identifying point in the first image of the video [4]. Both algorithms flag frames during which the instrument tip does not lie within the SAM2 mask resulting in HSV color segmentation being used to identify the instruments by their colored bands on the distal shaft. After 2D tip positions are attained in the four (2 cameras x 2 sensors per camera) views, object depth is calculated using an average of direct linear transformation (DLT) stereo triangulation, monocular on-axis back-projection, and monocular off-axis back projection. Instrument trajectory smoothing using is primarily done using the SAM2 and CoTracker3 algorithms as they have built-in temporal consistency, however for frames requiring HSV segmentation, the Savitzky-Golay algorithm is used for motion smoothing to reduce jerk artifacts. Finally, another HSV color check at each frame is used to ensure the green and pink color data is never transferred to the opposite instrument.
The software computes task-centric metrics: path length, idle/dwell time, velocity/acceleration profiles, tremor/smoothness indices, and workspace volume.
An Off-Axis Training Mode provides view orientation to reproduce visual-axis misalignment during simulation tasks (e.g., peg transfer, pattern cutting, knot tying).
The whole system runs on a single Jetson Orin with 64 Gb of RAM.

Result

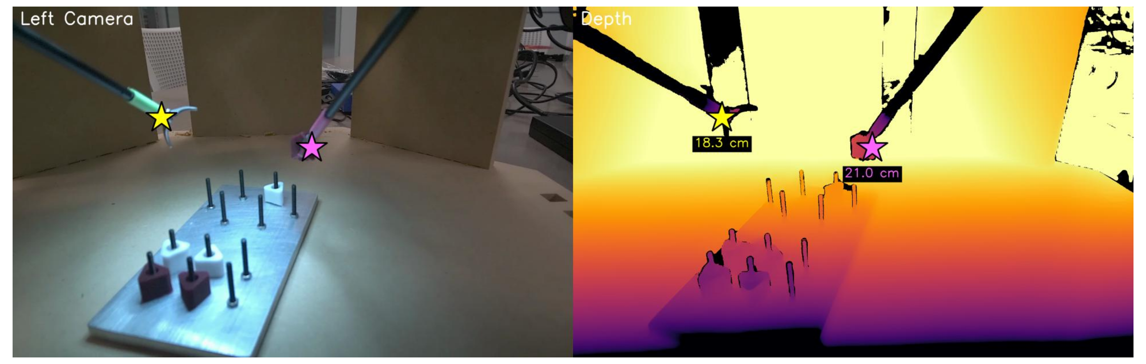
A



B

Metric	Operator A	Operator B	Unit
Workspace Volume	560.16	348.77	cm^3
Avg Speed	28.43	24.79	mm/s
Max Jerk (P95)	13,168.59	7,563.40	mm/s^3
Path Length	4,133.54	3,593.44	mm
Economy of Motion	0.029	0.023	ratio (0-1)
Total Time	73.10	75.18	s

C



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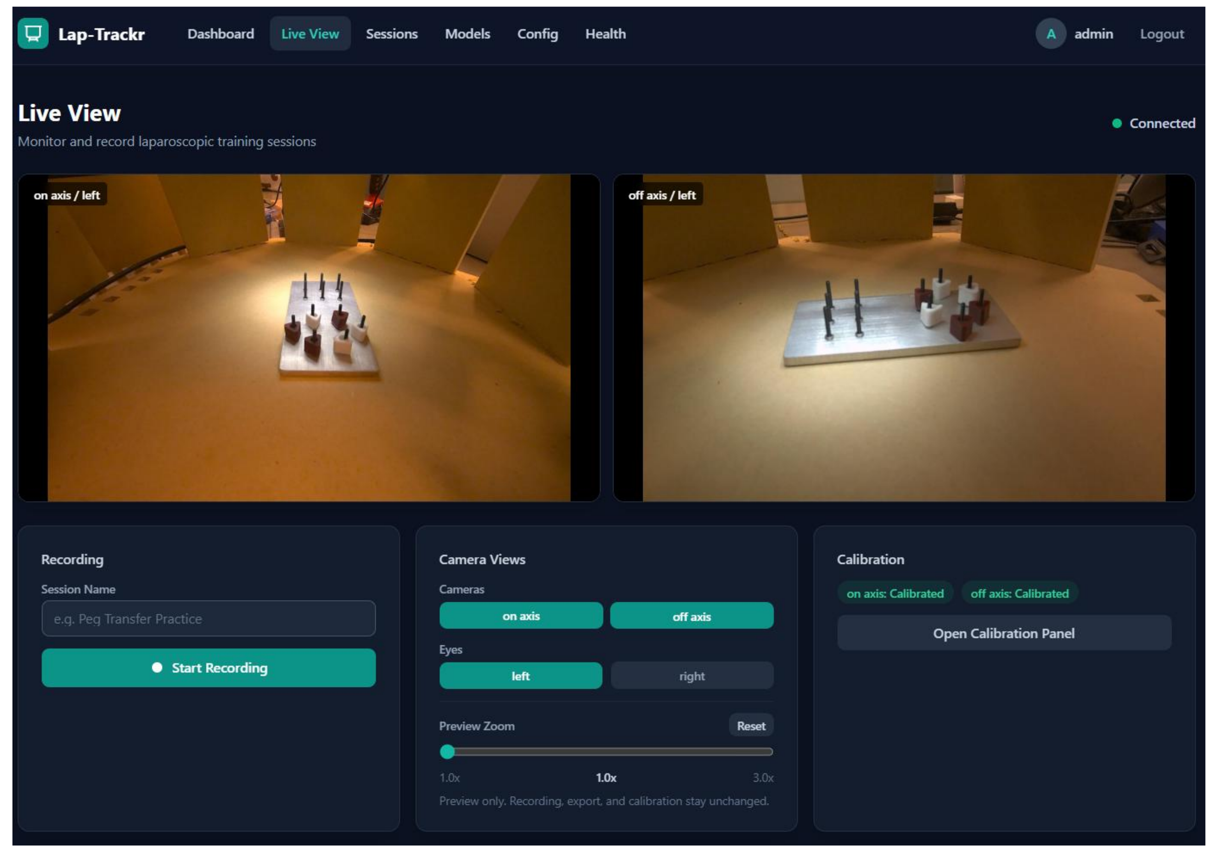

E

Figure 1. a) Workflow overview of the LapTrackr system, b) Pilot testing results from 2 users, c) Annotated user view and depth map of instruments inside the training enclosure., D) user software interface of the system, E) interior of the LapTrackr enclosure showing the light source, dual camera setup and access ports for laparoscopic instruments.

Results/Implications

A functioning prototype which runs offline on recorded training videos, producing per-instrument timelines and path length, idle/dwell time, velocity/acceleration profiles, tremor/smoothness indices, and workspace volume metrics.

Future Actions

This resident-focused, off-axis-aware analytics tool utilizes continuous motion data to support individualized coaching and competency decisions. Next steps include:

- Benchtop validation of reliability and convergent validity
- Prospective skills-lab study across PGY levels with post-hoc learner stratification
- Development of an "Off-Axis Performance Index”
- Multi-site replication

Additionally, future work will correlate the Lap-Trackr analytic metrics with OSATS scoring as a method of validation to further evaluate the effectiveness of this system in assessing surgical trainee competency in laparoscopic exercises.

If validated, the approach could help standardize assessment, accelerate progression, and enable scalable, data-driven surgical education while preserving learner privacy.

Acknowledgments

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