Barpath: Automated Olympic Weightlifting Analysis with Machine Learning and Computer Vision

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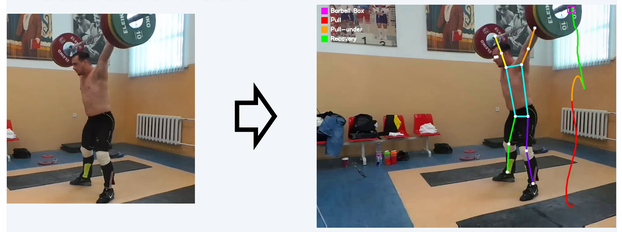
BACKGROUND

- Olympic weightlifting (snatch, clean & jerk) demands precise technique
- Wearable sensors (IMUs, force plates) are expensive and intrusive
- No tool provides lift-specific feedback for Olympic weightlifting
- Barpath fills this gap: a fully automated pipeline that extracts barbell trajectory, joint angles, and phase timing from standard video



MOTIVATION AND OBJECTIVES

Automated Detection: Identify barbell position and athlete pose in arbitrary training videos without calibration

Kinematic Extraction: Compute velocity, acceleration, specific power, and joint angles frame-by-frame

Phase Segmentation: Automatically split each lift into
Pull → Pull-under → Recovery

Technique Critique: Detect common faults (early arm bend, incomplete extension, slow turnover) via ML models

Real-Time Feedback: Provide live preview with bar path drawing and lift-type classification during recording

(Below) Frame-by-frame illustration of a single lift. This is what our program sees.

METHODOLOGY AND SYSTEM DESIGN

Barpath combines deep-learning barbell detection (YOLO) and pose estimation (MediaPipe) with biomechanical signal processing to extract kinematic features from weightlifting videos. A five-step pipeline produces stabilised bar paths, joint angles, velocity profiles, and technique scores by comparing lifter metrics against pro-athlete baselines. Real-time webcam preview mode provides instant lift classification and fault detection.

INPUT SOURCES

- **Video File (.mp4 / .mov)** — Recorded lift for post-processing
- **Live Camera Stream** — Real-time preview with instant feedback

STEP 1: DATA COLLECTION

Computer Vision Detection & Tracking → raw_data.pkl

- **YOLO Detection** — Barbell endcaps / frame
- **MediaPipe Pose** — 33 body landmarks + segmentation
- **Optical Flow** — Lucas-Kanade camera stabilisation

Threaded producer-consumer decoding. Auto-detects ONNX / OpenVINO / TensorRT.

STEP 2: KINEMATIC ANALYSIS

Biomechanical Feature Computation → final_analysis.csv

- **Smooth & Kinematics** — Savitzky-Golay + numerical diff
- **Phase Detection** — Pull / Pull-under / Recovery (t0–t4)
- **Joint Angles & Power** — Knee, elbow, specific power (W/kg)

Unpacks 14 landmarks into per-joint columns. Stabilises barbell position. ~40+ CSV columns.

STEP 3: GRAPH GENERATION

- **Trajectory Plots** — Phase-coloured bar path (X-Y)
- **Kinematic Charts** — Velocity, acceleration, power

Matplotlib PNGs @ 150 DPI. Phase bands + start/end markers.

STEP 4: TECHNIQUE CRITIQUE

- **Feature Extraction** — ~26 scalar features per lift
- **Baseline Comparison** — Pro athlete percentiles (p10–p90)

Rule-based scoring 0–100. 17 fault types. Coaching cues + checklist.

STEP 5: VIDEO RENDERING

- **Frame Overlays** — Bar path, skeleton, barbell box
- **Composite + Audio Mux** — ffmpeg H.264 MP4 output
- **Technical Overlay** — Progress bar + metrics

Shake-compensated path. Phase legend. GC every 50 frames.

SYSTEM OUTPUTS

- **final_analysis.csv** — Per-frame kinematic data + phases + predictions
- **Graph Images (5×)** — Trajectory, velocity acceleration, power charts
- **Annotated Video** — Overlay bar path & joints, fault markers
- **analysis.md** — Biomechanical report Score, faults, coaching cues

Batch mode: superimposed_bar_paths.png for multi-lift comparison

LIVE PREVIEW MODE (Real-Time)

Webcam stream with instant lift detection & technique feedback

IDLE (Buffer frames) → TRIGGERED (Bar passes knees) → RECORDING (Capture + bar path) → CLASSIFYING (Random Forest model) → DISPLAYING (Result 3 s → reset)

Trigger: bar crosses below knees OR vertical velocity > 25 px/frame. Displays lift type + top fault.

Draws: YOLO boxes, skeleton, phase-coloured bar path, FPS counter. Runs on a background thread.

Output Files (per analysis run)

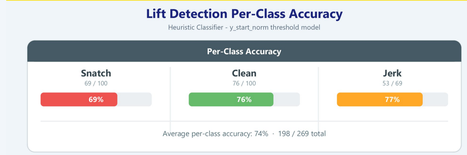
FILENAME	PURPOSE	PRODUCED BY
raw_data.pkl	Intermediate: raw landmarks, barbell coordinates, shake vectors	Step 1
final_analysis.csv	Complete analysis table: 40+ kinematic columns per frame	Step 2
barbell_xy_stable_path.png	Smoothed X-Y bar path, coloured by lift phase	Step 3
vel_y_smooth_graph.png	Vertical velocity over time with phase shading bands	Step 3
accel_y_smooth_graph.png	Vertical acceleration over time with phase shading	Step 3
specific_power_y_smooth_graph.png	Specific power (W/kg) over time with phase shading	Step 3
analysis.md	Technique report: score, faults, coaching cues, checklist	Step 4
output.mp4	Annotated video with path, skeleton, and legend overlay	Step 5

Legend: Input · Collection · Analysis · Graphs · Critique · Rendering · Live Preview · Output

RESULTS AND ANALYSIS

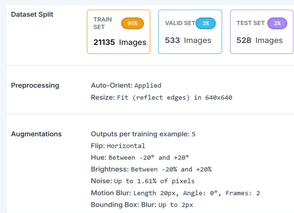
Lift Detection System

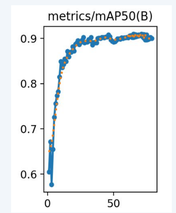
- Barbell object detection: ~90% mAP@50
- Trained on 299 lifts from elite weightlifters (Olympic/world champions)
- Individual clean followed by jerk are reactively concatenated to analyze clean+jerk (fourth lift type)
- Overall Detection Accuracy: 74%



Object Detection Model

- Our YOLO barbell detection model was trained on a dataset of ~5,200 hand-labeled images, which we augmented to >22,000
- After training, our model achieved 90.6% mAP@50 accuracy





CONCLUSION AND FUTURE WORK

What We Achieved

- Fully automated weightlifting analysis
- Real-time lift recognition
- Open-source architecture

Future Directions

Expand dataset: Include female lifters
Temporal modeling: Replace Random Forest with LSTM/Transformer for sequential fault detection
Feedback loop: Integrate with training logs to track technique improvements over time
Automatic barbell weight estimation: Use bar deformation + disc diameter to estimate load

Check out the project on Github!