Real-Time Biomechanical Feedback for Injury Prevention and Performance Optimization in Baseball Pitching

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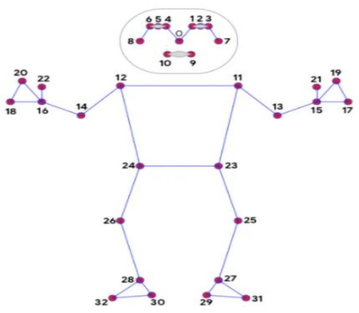
Background

- Sports injuries, particularly in high-impact and repetitive-motion sports like baseball, pose significant challenges to both players' health and team performance.
- Pitching-related injuries are a leading cause of long-term mechanical inefficiencies, lost playing time, and financial burdens for teams.
- While existing biomechanical tracking tools provide valuable data, most rely on post-game analysis, delaying injury prevention interventions
- There is a growing need for real-time biomechanical monitoring to enable instant corrections, reduce injury risk, and enhance performance longevity.
- **PitchPerfectAI** was developed to fill this gap, it integrates **pose estimation** with **clinically informed angle thresholds** to monitor biomechanics in real time.
- By embedding **orthopedic benchmarks** into its feedback engine. flags dangerous deviations before translating into injury

Objectives

- To develop an AI-powered system capable of providing real-time biomechanical feedback to pitchers during pitching.
- To utilize expert orthopedic benchmarks (e.g., shoulder external rotation below ~170° indicate a stiff or improperly timed shoulder motion, abduction ~90°, elbow flexion ~90–120°) to guide injury prevention..

Human Pose Estimation Using Mediapipe



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10. mouth_right
11. left_shoulder
12. right_shoulder
13. left_elbow
14. right_elbow
15. left_wrist
16. right_wrist
17. left_pinky
18. right_pinky
19. left_index
20. right_index
21. left_thumb
22. right_thumb
23. left_hip
24. right_hip
25. left_knee
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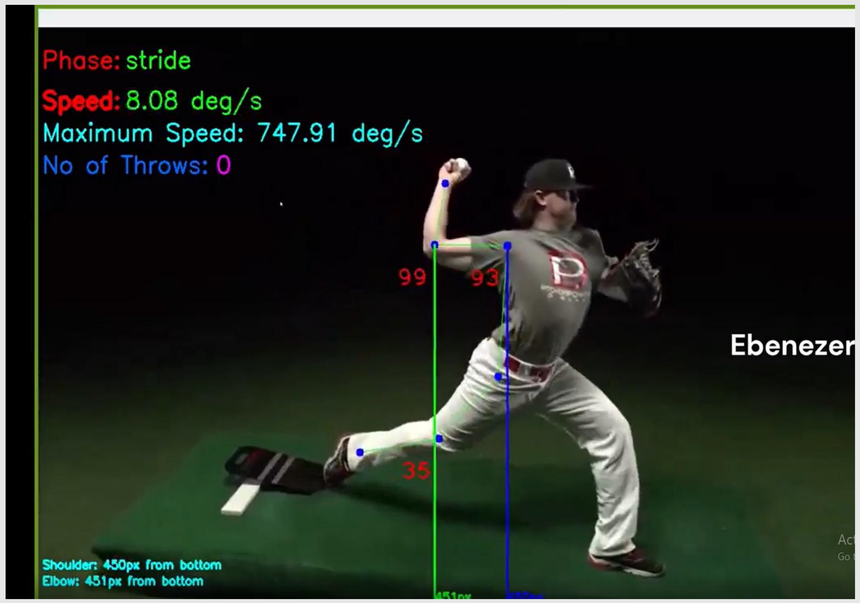

Method

Pose Detection Framework

The system utilizes Google's MediaPipe to detect and track 33 3D body landmarks. Real-time pose estimation is enabled by configuring detection confidence (≥0.7) and tracking thresholds, with smoothing applied for landmark stability.

Live Motion Capture

A webcam captures athlete movement at 30 frames per second. MediaPipe processes each frame to extract joint positions specifically shoulder, elbow, hip, and trunk landmarks

Goniometric Angle Measurement, Standardization via Interpolation

Custom angle calculation functions compute joint angles (e.g., shoulder external rotation) using vector geometry between landmarks. Angles are normalized to 0–100% based on user-defined biomechanical thresholds, ensuring consistency across athletes and sessions

Real-Time Feedback Loop

When an athlete deviates from normative biomechanical ranges (e.g., external rotation >180°, elbow flexion <90°), the system generates immediate visual and/or auditory feedback.

Error detection and Correction Prompts

Deviations trigger targeted correction cues (e.g., "raise elbow," "too much should rotation," facilitating in-the-moment technique adjustments to mitigate injury risks.

Results

Joint &Metric	Normative Range	Deviation Meaning	Risk/Alerts Triggered
Shoulder External Rotation	170–180° during cocking	<170°: limited range → shoulder stiffness, poor velocity	Risk: joint overload, velocity loss
		>180°: hypermobile → excessive layback	Risk: labrum strain, rotator cuff instability
Shoulder Abduction	85–95° arm-out angle	<80°: low slot → loss of leverage	Risk: reduced velocity, impingement.
		>100°: high slot → upward torque overload	Risk: shoulder compression or scapular dyskinesis
Elbow Flexion	90–120° at cocking phase	-<90°: overly extended arm	Risk: valgus stress → UCL strain
		>120°: tucked elbow → inefficient transfer	Risk: timing disruption, strain on biceps tendon

Discussion

PitchPerfectAI bridges clinical biomechanics and real-time AI feedback to detect and correct motion

Fatigue Detection Patterns:

- Gradual ↓ in **shoulder ext. rotation/elbow flexion range** over repeated pitches suggests **mechanical fatigue**.
- **Early trunk opening** becomes more likely as **core fatigue** sets in—linked to increased shoulder stress late in games.
- Repeated alerts within a short sequence (e.g., **3 deviations in 5 pitches**) flag **neuromuscular fatigue onset**, guiding pitch limits or substitution decisions.

Conclusions

It offers an effective, non-invasive solution for biomechanical feedback in baseball and beyond. Applications include:

- On-the-spot mechanical correction for athletes
- Monitoring of return-to-throw protocols in sports medicine
- `Digital rehab programs (e.g., post-stroke, joint recovery)
- Coaching and biomechanics education tools for injury prevention

References & additional information