NASM Overhead Squat Assessment (OHS)

Deterministic Biomechanical Algorithm Documentation

Project Title

Deterministic Biomechanical Assessment of the NASM Overhead Squat Using 3D Motion Capture Data

1. Overview

This project implements a rule-based biomechanical assessment system for the NASM Overhead Squat (OHS) using 3D motion-capture joint coordinate data.

The objective is to automatically detect and classify common movement compensations defined by NASM standards, without the use of machine learning.

Primary Assessment Targets

Anterior (Frontal) View

- Knee deviation (valgus / varus)

Lateral (Sagittal) View

- Excessive lumbar extension (low-back arch)
- Excessive forward torso lean

The system integrates:

- Crenna-aligned biomechanical signal filtering
- Vector-based geometric joint-angle modeling
- Phase-specific movement analysis
- Threshold-based NASM classification
- 3D skeletal visualization for interpretability

All outputs are **numerically reproducible, biomechanically interpretable, and visually verifiable**.

2.Algorithm Pipeline

The analysis pipeline is fully deterministic and consists of seven sequential stages.

Step 1: Data Ingestion

- Input data consist of Excel files containing time-series 3D joint coordinates obtained from a motion-capture system.
- Joint naming conventions are standardized (lowercase, trimmed) to ensure consistent numerical processing.
- Each file is processed independently to preserve experimental integrity.

Step 2: Biomechanical Signal Filtering (Crenna-Aligned)

To ensure biomechanical validity of joint trajectories, **zero-phase Butterworth low-pass filtering** is applied.

Method

- 4th-order Butterworth low-pass filter
- Cutoff frequency: 6Hz
- Sampling rate: 30 Hz
- Implemented using forward-backward filtering (filtfilt)

Rationale

- Removes high-frequency motion-capture noise
- Preserves temporal alignment (no phase distortion)
- Complies with Crenna et al.'s recommendations for human movement analysis

Reference

Crenna, F., Rossi, G. B., & Berardengo, M. Filtering Biomechanical Signals in Movement Analysis

Step 3: Phase-specific Squat Depth Detection

NASM movement compensations are most pronounced at maximum squat depth.

Detection Strategy

- Vertical displacement of the waist (waist_y) is analyzed
- Frames corresponding to the lowest 20% of the vertical position are selected
- Only these frames are used for biomechanical evaluation

Purpose

- Focus analysis on the most diagnostically relevant phase
- Reduce variability from non-critical movement segments

Step 4: Geometric Joint-Angle Modeling

All biomechanical metrics are computed using vector-based kinematics, ensuring deterministic and anatomically interpretable results.

4.1 Knee Deviation (Frontal Plane)

- Computed using hip–knee–ankle vectors in the frontal plane
- Angle represents deviation from neutral knee alignment
- Larger values indicate increased valgus or varus motion

4.2 Lumbar Extension (Sagittal Plane)

- Computed using torso–waist–hip vectors
- Estimates excessive lumbar arching during the squat
- Uses mid-hip position for bilateral stability

4.3 Forward Torso Lean

- Angle between torso vector and global vertical axis
- Quantifies anterior trunk inclination relative to upright posture

Implementation

- All angles are computed using a normalized vector dot-product formulation
- Output is expressed in degrees
- Final metric values are averaged across bottom-phase frames

Step 5: Rule-Based NASM Classification

Each biomechanical metric is classified using explicit NASM-aligned thresholds.

Classification	Criteria
NORMAL	Within acceptable alignment
MILD	Minor deviation
FAULT	Excessive or compensatory movement

Key Characteristics

- No machine learning or statistical inference
- Purely deterministic decision logic
- Fully reproducible across datasets

Step 6: 3D Skeletal Visualization

To support interpretability and qualitative validation, the system generates frame-by-frame 3D skeletal GIFs.

Visualization Features

- Anatomically connected joint segments
- Fixed orthographic projection
- Consistent spatial scaling
- Frame indexing and labeling

Purpose

- Visual confirmation of detected compensations
- Reporting and presentation support
- Transparency of algorithm decisions

Step 7: End-to-end Pipeline Execution

For each motion-capture dataset:

1. Load and standardize joint coordinate data
2. Apply Crenna-aligned signal filtering
3. Detect squat bottom phase
4. Compute geometric joint angles
5. Apply NASM rule-based classification

6. Generate 3D skeletal visualization

The pipeline executes autonomously for all input files.

3.Key Design Principles

Deterministic Architecture

- Identical inputs always produce identical outputs
- Suitable for clinical, educational, and research use

Biomechanical Validity

- Signal filtering and angle modeling align with established biomechanics literature

Interpretability

- Every numerical output corresponds to a physically meaningful quantity
- Visualization enables human verification

4. Summary

This system delivers a **complete, deterministic NASM Overhead Squat Assessment framework** by integrating:

- Crenna-aligned signal processing
- Vector-based biomechanical modeling
- Phase-specific movement analysis
- Rule-based NASM classification
- Interpretable 3D visualization

The algorithm transforms raw 3D joint trajectories into **clinically meaningful movement assessments**, ensuring **robustness, transparency, and reproducibility** suitable for **sports science, rehabilitation, and human-movement research**.