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FitCoachAR: Automated Coaching Feedback System

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CAS 741 - Development of Scientific Computing Software

Goal Statements

- G1: Analyze user video input to detect skeletal landmarks in 2D space.($\mathbb{R}^2$).
- G2: Verify movement execution against established biomechanical thresholds (e.g., joint angles).
- G3: Provide corrective feedbacks
- G4: Quantify repetition

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Example Scenario: Squat Depth Analysis

- Input: A frame from the video stream showing a user performing a squat.
- Landmark Extraction: Identify coordinates for Hip (P_H), Knee (P_K), and Ankle (P_A).
- Calculation:
  - Construct vector $\vec{v}_1$ from Knee to Hip.
  - Construct vector $\vec{v}_2$ from Knee to Ankle.
  - Calculate the interior angle θ_{knee}
- Verification:
  - Rule: If $\theta_{knee} < 90°$, the rep is valid.
- Output:
  - Status = "Good Depth" or "Too High".
  - Counter = counter+1

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Assumptions

- A1: The camera frame is fixed relative to the user
- A2: The user performs the exercise selected in the input interface.
- A3: The relevant joints are visible within the camera frame
- A4: The exercise is performed in a 2D plane perpendicular to the camera axis.
- A5: Lighting conditions are sufficient for the underlying pose estimation model to detect keypoints with confidence score > 0.5.

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Inputs & Outputs

- Input Variables:
  - Video Stream: Sequence of images $I \in \mathbb{N}^{W \times H \times 3}$ (RGB).
  - Exercise Type: $E \in \{\text{Squat}, \text{bicep curl}\}$ (Selected by user)
  - Calibration Data: Initial set of N repetitions to establish baseline Range of Motion (ROM)
- Output Variables:
  - Visual Guidance: e.g., directional vectors
  - Corrective Feedback: Discrete messages (e.g., "Depth OK", "Knees Inward").
  - Session Summary: Aggregate statistics (N_{reps}, Avg Quality Score) presented post-exercise.

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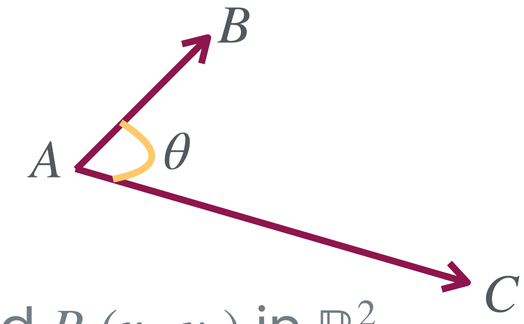
Theoretical Models (TM)

- TM1: **Vector Angle** Given three points A, B, C forming two vectors $\overrightarrow{BA}$ and $\overrightarrow{BC}$:
- Formula: $\theta = \arccos\left(\frac{\overrightarrow{BA} \cdot \overrightarrow{BC}}{|\overrightarrow{BA}||\overrightarrow{BC}|}\right)$



- TM2: **Euclidean Distance** Given two points $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$ in $\mathbb{R}^2$
- Formula: $d(t) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$

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Instanced Models

- **IM1: Personalized Calibration**
  - Goal: Define user-specific safety bounds instead of hardcoded angles.
  - Process:
    - Record some reps.
    - Calculate average minimum angles (θ_{min_avg}).
    - Threshold Definition: Set valid range $[\theta_{min_{avg}} - \delta, \theta_{min_{avg}} + \delta]$.
  - **IM2: Repetition Logic**
    - State machine: $Start \rightarrow near\ max\ Bend \rightarrow Max\ Bend \rightarrow Return$
    - A repetition is counted when the user completes the cycle and returns to the starting position.
  - **IM3: Joint Stability**
    - CheckRefines: Euclidean Distance Model.
    - Logic: Monitor displacement $d(t)$ of a specific joint relative to another or itself.
    - Rule: Trigger warning if $d(t) > Threshold$.

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Open Questions

- Current assumption: Ignore frames with occlusion.
  - Is this assumption acceptable or must we infer missing keypoints?
- We lack a "Ground Truth" for 2D video data.
  - How to validate our 2D geometric models without expensive 3D motion capture equipment?
  - State Machine Definition:
    - What is the minimal set of optimal states required to robustly define a repetition?

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Thank You

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