High Risk Project Assignment

Deadlift Decoded: An AI Approach to Perfecting the Pull

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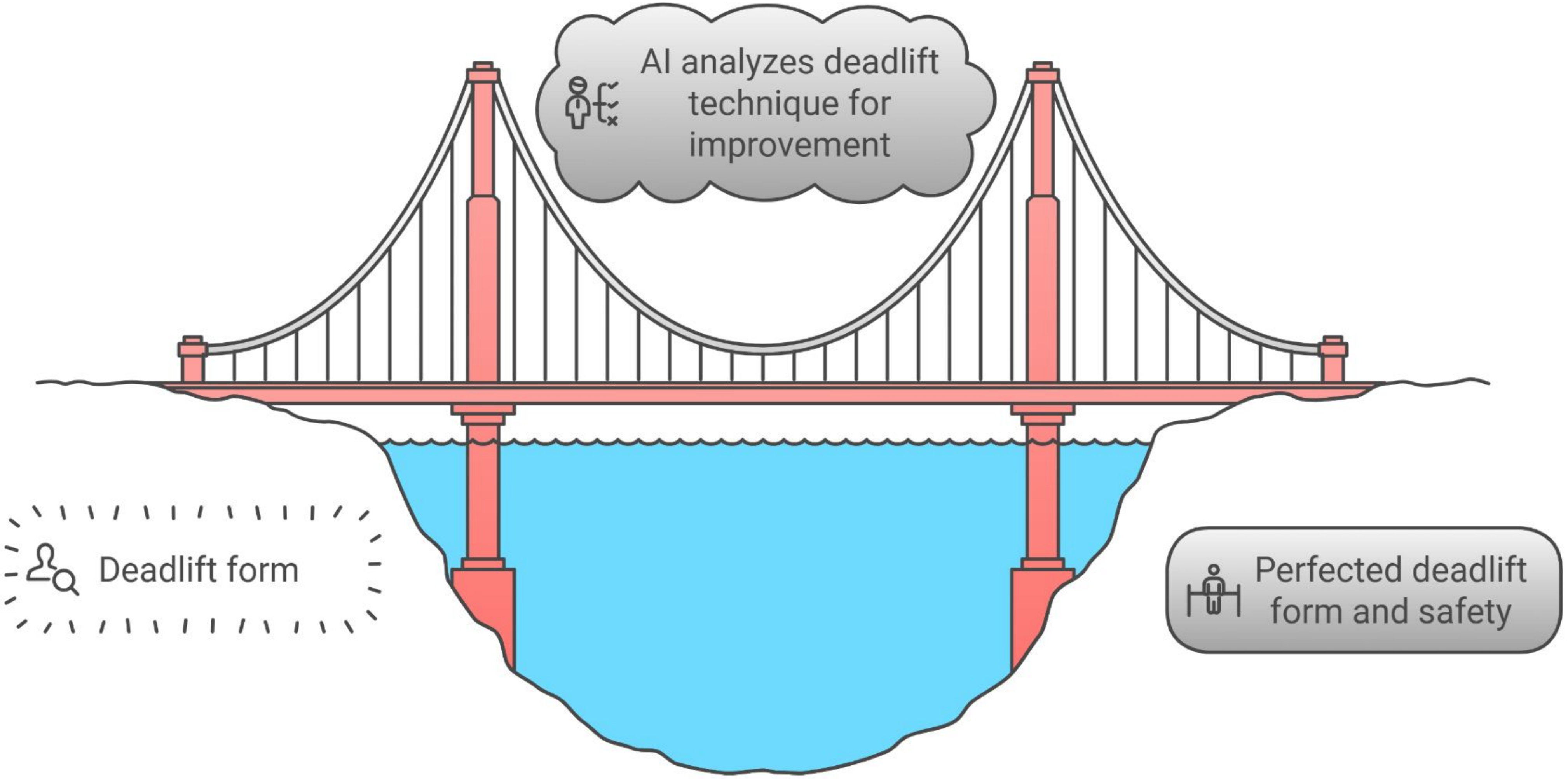
Enhance Deadlift Technique with AI Feedback

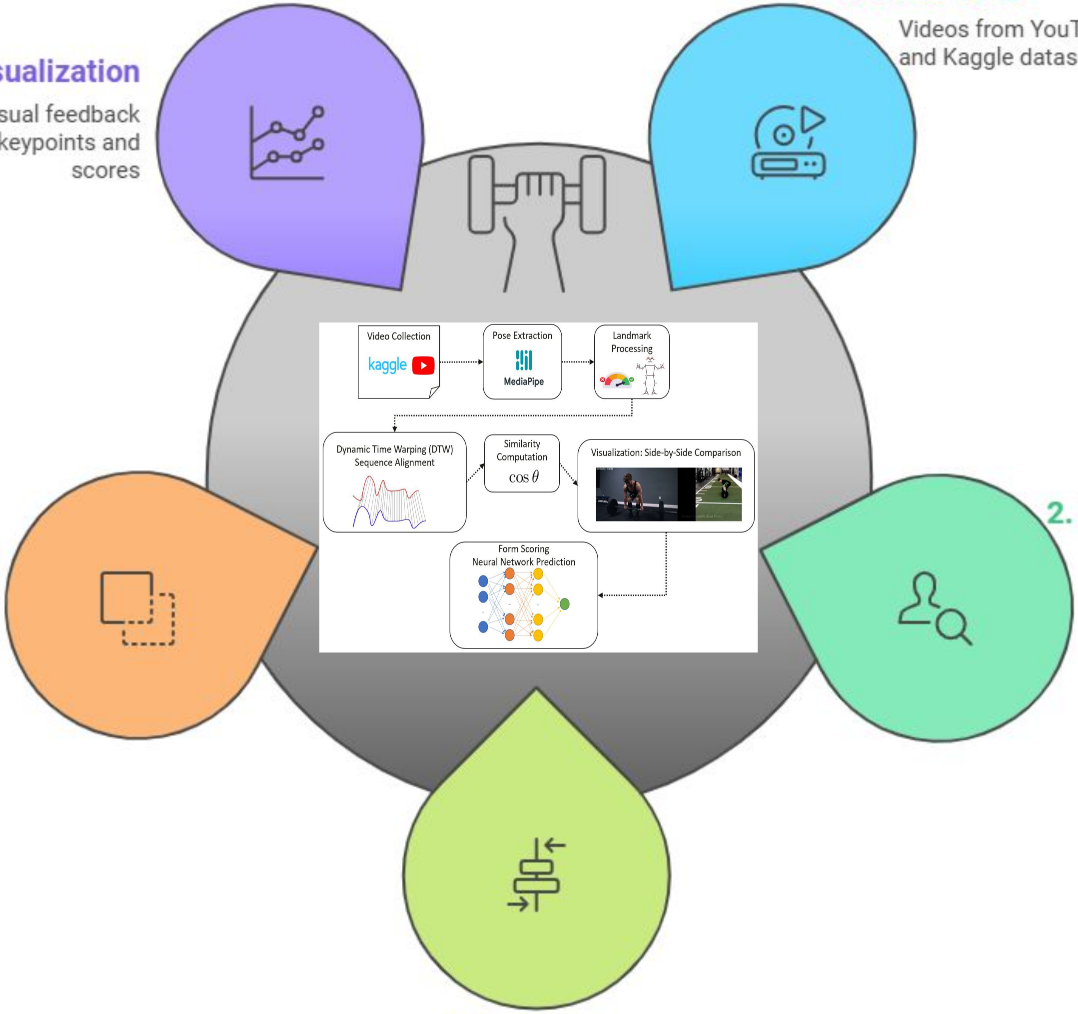


Introduction
(Continued…)

Sample Deadlift form (Good vs. Bad)

Data & Methodology

Our methodology followed these key steps:



1. Video Data
Videos from YouTube and Kaggle datasets

2. Pose Detection
MediaPipe Pose model detecting key landmarks

3. Sequence Alignment
Dynamic Time Warping for synchronized data

4. Similarity Computation
Weighted cosine similarity using confidence scores

5. Visualization
Visual feedback showing keypoints and scores

Data & Methodology
(Continued…)

#1. Data Sources:

- We used deadlift videos from YouTube and the Kaggle Gym Workout Exercises Dataset.
- However, data quality issues, such as incomplete repetitions, limited the accuracy of our model, hindering its ability to assess proper form.

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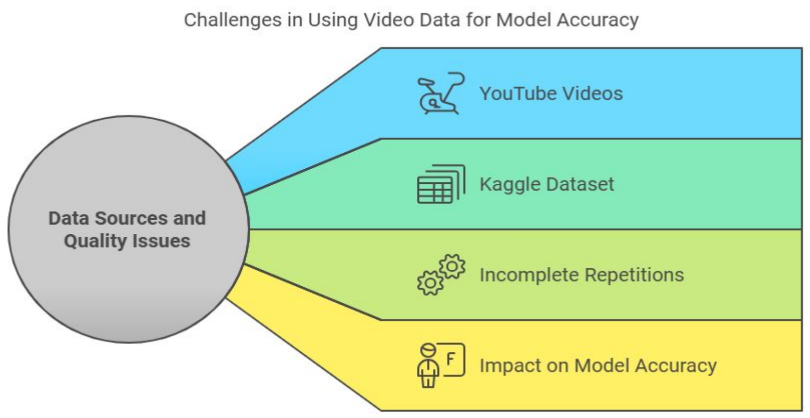
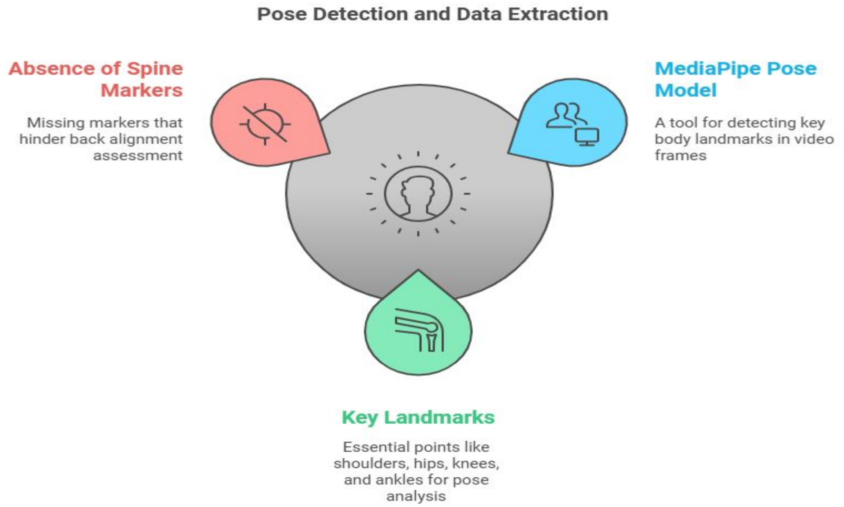


#2. Pose Detection and Data Extraction:

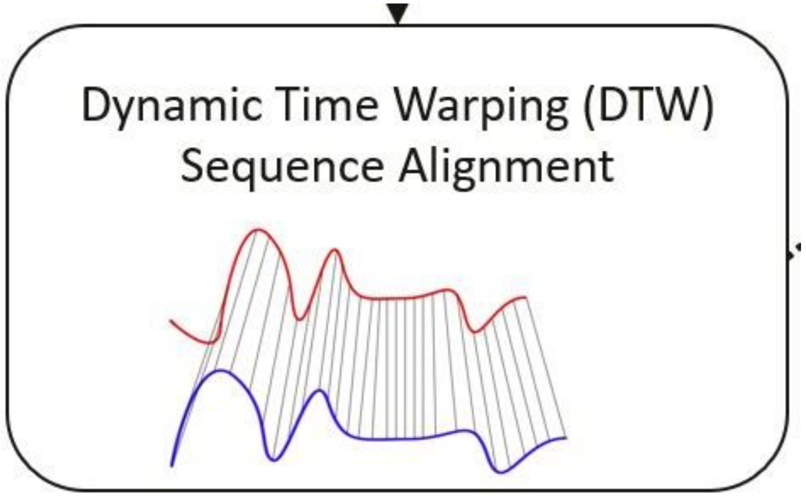
- We used the MediaPipe Pose model to detect key landmarks (shoulders, hips, knees, and ankles) in video frames.
- However, the absence of spine markers made it difficult to assess back alignment, limiting the form analysis accuracy.



Data & Methodology
(Continued…)

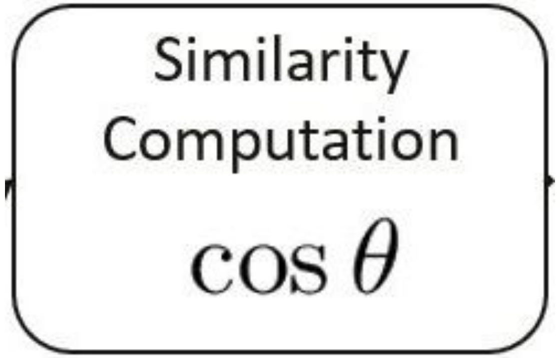
#3. Sequence Alignment with DTW:

- To account for varying exercise speeds, Dynamic Time Warping (DTW) was applied to align video sequences based on keypoint positions, ensuring synchronized data for comparison.



#4. Similarity Computation:

- We calculated similarity between reference and user videos by computing a weighted cosine similarity for each frame, using confidence scores to prioritize accurate detections.



Data & Methodology
(Continued…)

#5. Visualization and Feedback:

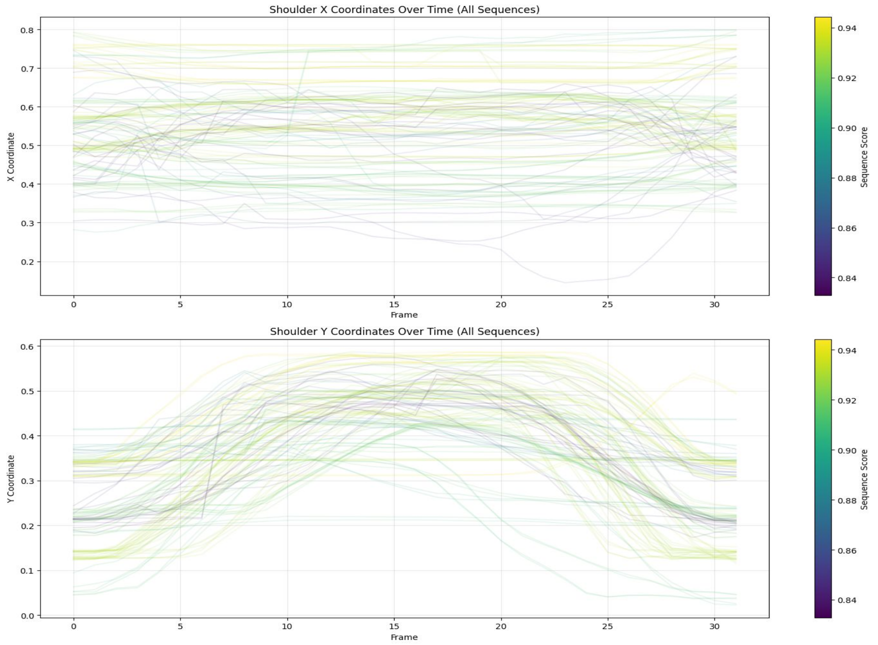
- The system visualizes comparisons between the user’s and reference sequences, showing keypoints, confidence scores, and similarity scores, helping identify form deviations and providing actionable feedback

Results

Key Findings from Deadlift Rep Detection Analysis (Continued…)

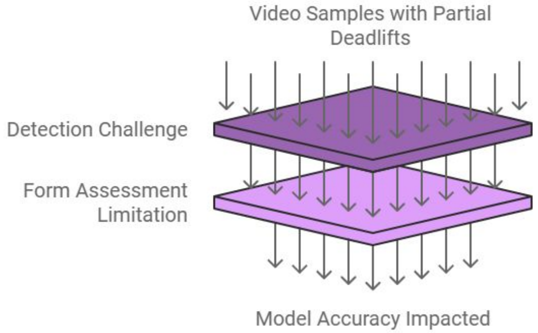
#1. Shoulder Height Over Time

- Shoulder movement tracked in both horizontal (x) and vertical (y) directions.
- The x-axis showed consistent back-and-forth motion; the y-axis revealed the deadlift lifting curve.



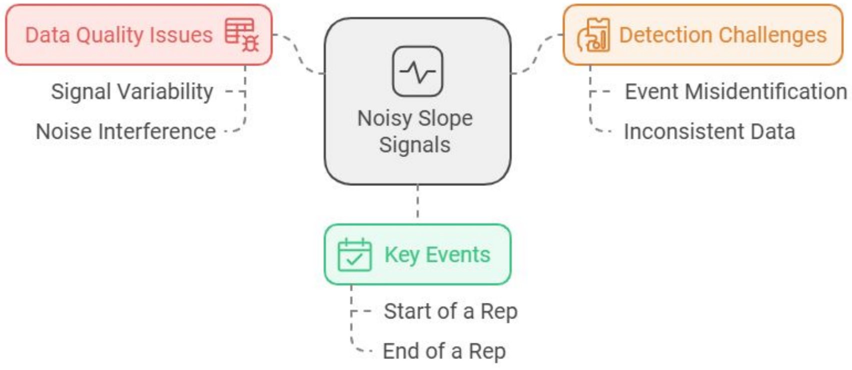
#2. Incomplete Repetitions

- ~100 video samples featured partial deadlifts.
- Many reps did not complete the full movement, limiting model's ability to detect full repetitions and assess form.



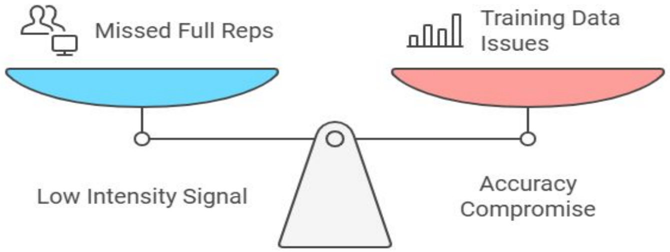
#3. Noisy Slope Signals

- Significant signal variability indicated data quality issues.
- Made it difficult to detect key events (e.g., start and end of a rep).



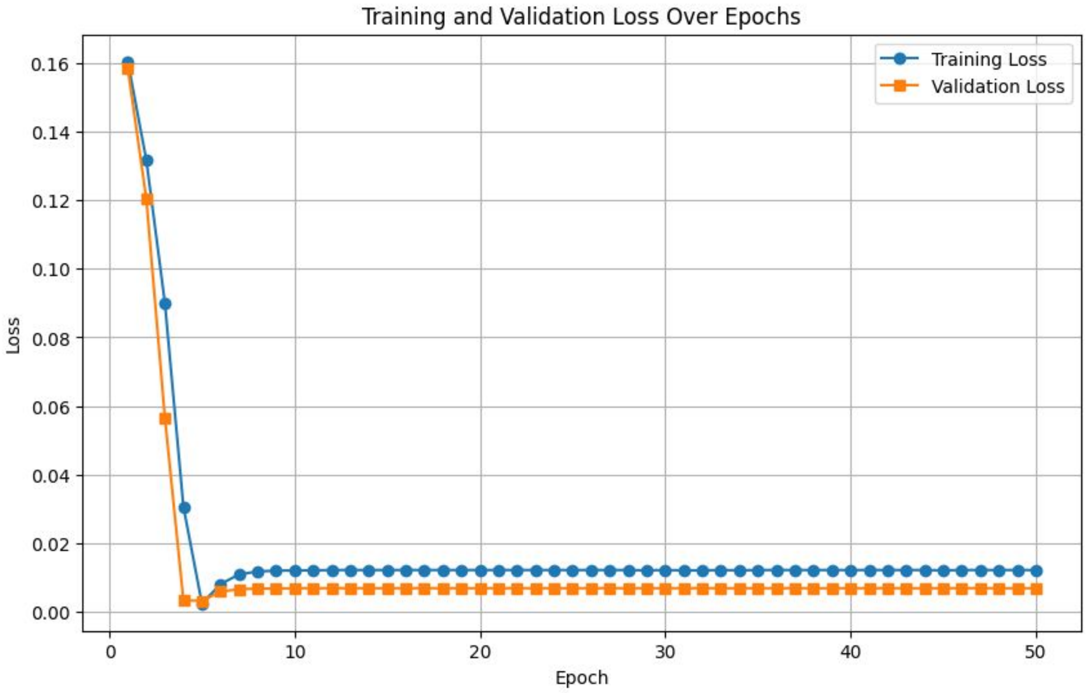
#4. Limitations of Detected Reps

- Low intensity of "Detected Rep" signal, missing many full reps.
- Compromised the accuracy of the model's training data.



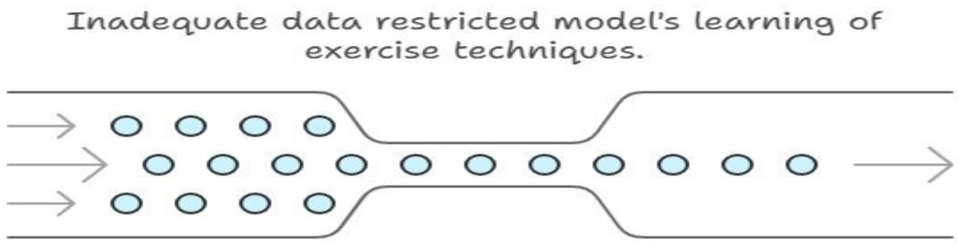
#5 . Training and Validation Loss:

- *Despite the data challenges, careful data preprocessing and hyperparameter tuning helped to improve the model.*
- The training loss decreased quickly, and both training and validation losses stabilized at low levels, with minimal overfitting observed, indicating good model performance.



#1. Importance of High-Quality Training Data:

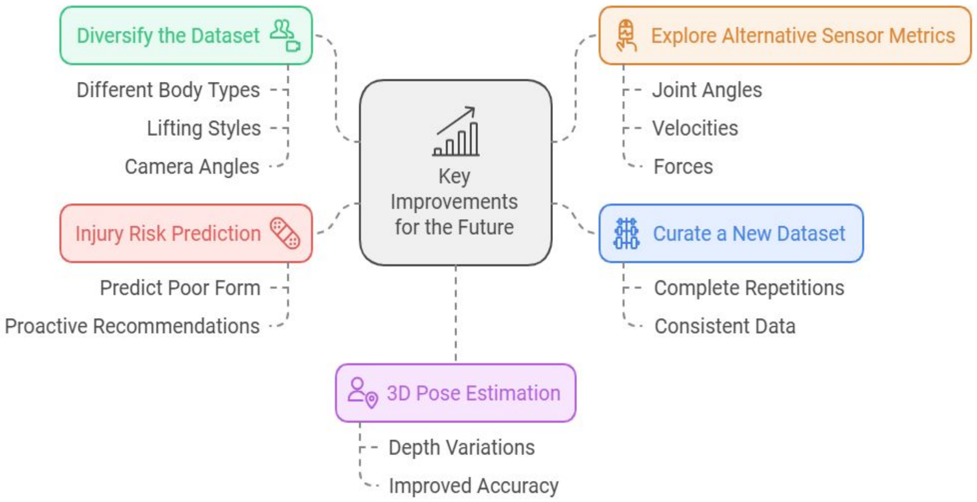
- This project underscores the necessity of high-quality training data for developing machine learning models that analyze exercise form.
- The dataset used in this study had key limitations that hindered the model's ability to accurately learn proper deadlift technique.



Future Directions
(Continued…)

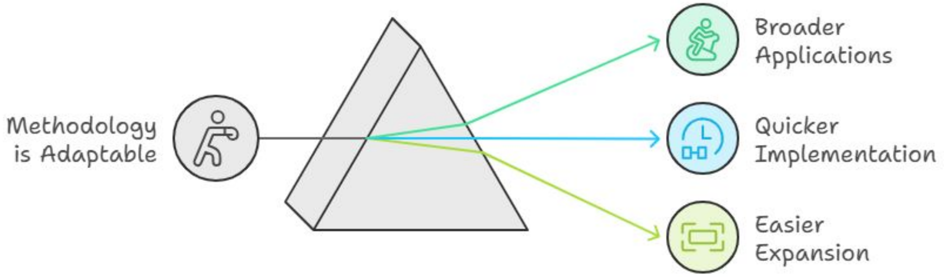
#2. Key Improvements for the Future:

- **Curate a New Dataset**: Focus on collecting complete and consistent deadlift repetitions.
- **Diversify the Dataset**: Increase the variety of video examples, including different body types, lifting styles, and camera angles, to improve model generalization.
- **Explore Alternative Sensor Metrics**: Integrate additional biomechanical measurements like joint angles, velocities, and forces for a richer feature set.
- **Injury Risk Prediction**: Enhance the model to predict injury risks based on poor form and provide proactive recommendations to prevent injuries.
- **3D Pose Estimation**: Implement 3D pose estimation to improve the accuracy of landmark detection, especially for movements with depth variations.



#3. Flexibility of the Approach:

- This methodology is adaptable, allowing the same framework to be applied to other exercises like squats or bench presses by changing the training data and target landmarks.
- This flexibility supports broader applications, quicker implementation, and easier expansion to other exercises.



Demo
(Code)

```
[ ] !pip install opencv-python numpy matplotlib mediapipe google-colab fastdtw scipy
```

Show hidden output

```
[ ] !pip install fastdtw scipy matplotlib
```

Show hidden output

```
[ ] from google.colab import drive
    drive.mount('/content/drive')
```

```
Drive already mounted at /content/drive; to attempt to forcibly remount, call drive.mount("/content/drive", force_remount=True).
```

```
[ ] import cv2
    import numpy as np
    import mediapipe as mp
    import os
    from tqdm import tqdm
    from glob import glob
```

```
from fastdtw import fastdtw
from scipy.spatial.distance import cosine
from dataclasses import dataclass
from typing import List, Tuple, Optional
import matplotlib.pyplot as plt
```

```
[ ] @dataclass
    class ProcessedSequence:
        """Container for processed video sequence data"""
        frames: np.ndarray  # Original video frames
        landmarks: np.ndarray  # Extracted pose landmarks
        timestamps: np.ndarray  # Frame timestamps
        confidence_scores: np.ndarray  # Landmark confidence scores
```

```
[ ] class DeadliftProcessor:
        def __init__(self, confidence_threshold: float = 0.3):
            self.mp_pose = mp.solutions.pose
            self.pose = self.mp_pose.Pose(
                static_image_mode=False,
                min_detection_confidence=0.7,
                model_complexity=1
            )
            self.confidence_threshold = confidence_threshold

            # Key points particularly important for deadlift form
            self.KEY_POINTS = [
                self.mp_pose.PoseLandmark.LEFT_SHOULDER,
                self.mp_pose.PoseLandmark.RIGHT_SHOULDER,
                self.mp_pose.PoseLandmark.LEFT_HIP,
                self.mp_pose.PoseLandmark.RIGHT_HIP,
                self.mp_pose.PoseLandmark.LEFT_KNEE,
                self.mp_pose.PoseLandmark.RIGHT_KNEE,
                self.mp_pose.PoseLandmark.LEFT_ANKLE,
                self.mp_pose.PoseLandmark.RIGHT_ANKLE
            ]

        def align_sequences(self, seq1: ProcessedSequence, seq2: ProcessedSequence) -> Tuple[ProcessedSequence, ProcessedSequence]:
          # Compute DTW path
          # Use only landmarks for computing the warping path
          distance_matrix = np.zeros((len(seq1.landmarks), len(seq2.landmarks)))
          for i in range(len(seq1.landmarks)):
              for j in range(len(seq2.landmarks)):
                  distance_matrix[i, j] = np.linalg.norm(seq1.landmarks[i] - seq2.landmarks[j])

          _, path = fastdtw(seq1.landmarks, seq2.landmarks, dist=lambda x, y: np.linalg.norm(x - y))
          path = np.array(path)

          # Create aligned sequences using the DTW path
          aligned_seq1 = ProcessedSequence(
              frames=seq1.frames[path[:, 0]],
              landmarks=seq1.landmarks[path[:, 0]],
              timestamps=seq1.timestamps[path[:, 0]],
              confidence_scores=seq1.confidence_scores[path[:, 0]]
          )

          aligned_seq2 = ProcessedSequence(
```

```
[ ]           confidence_scores=seq2.confidence_scores[path[:, 1]]
          )

          return aligned_seq1, aligned_seq2

        def compute_similarity(self, seq1: ProcessedSequence, seq2: ProcessedSequence) -> Tuple[float, np.ndarray, Tuple[ProcessedSequence, ProcessedSequence]]:
            """
            Compute weighted similarity between two sequences of different lengths.

            Args:
                seq1, seq2: ProcessedSequences to compare
            Returns:
                Tuple containing:
                - Overall similarity score
                - Array of frame-by-frame similarities
                - Tuple of aligned sequences for visualization
            """
            # First align the sequences
            aligned_seq1, aligned_seq2 = self.align_sequences(seq1, seq2)

            frame_similarities = []
            for i in range(len(aligned_seq1.landmarks)):
                # Combine confidence scores
                weights = aligned_seq1.confidence_scores[i] * aligned_seq2.confidence_scores[i]
                weights = weights / (np.sum(weights) + 1e-6)  # Add small epsilon to avoid division by zero

                # Weight the landmarks
                weighted_landmarks1 = aligned_seq1.landmarks[i] * np.repeat(weights, 3)
                weighted_landmarks2 = aligned_seq2.landmarks[i] * np.repeat(weights, 3)

                # Compute similarity
                sim = 1 - cosine(weighted_landmarks1, weighted_landmarks2)
                frame_similarities.append(sim)

            return (
                np.mean(frame_similarities),
                np.array(frame_similarities),
                (aligned_seq1, aligned_seq2)
            )

        def process_video(self, video_path: str) -> Optional[ProcessedSequence]:
            """
            Process a video file and extract pose sequences with timing information.

            Args:
                video_path: Path to video file
            Returns:
                ProcessedSequence or None if processing fails
            """
            cap = cv2.VideoCapture(video_path)
            if not cap.isOpened():
                raise ValueError(f"Could not open video file: {video_path}")

            frames = []
            landmarks = []
            timestamps = []
            confidence_scores = []

            frame_count = 0
            fps = cap.get(cv2.CAP_PROP_FPS)

            while cap.isOpened():
                ret, frame = cap.read()
                if not ret:
                    break

                # Calculate timestamp in milliseconds
                timestamp = (frame_count / fps) * 1000
                frame_count += 1

                frame_rgb = cv2.cvtColor(frame, cv2.COLOR_BGR2RGB)
                results = self.pose.process(frame_rgb)

                if results.pose_landmarks:
                    frame_landmarks = self._extract_keypoints(results.pose_landmarks)
                    frame_confidence = self._get_confidence_scores(results.pose_landmarks)

                    if np.mean(frame_confidence) > self.confidence_threshold:
                        frames.append(frame)
                        landmarks.append(frame_landmarks)
                        timestamps.append(timestamp)
                        confidence_scores.append(frame_confidence)
```

Demo
(Code)

```python
                confidence_scores.append(frame_confidence)

        cap.release()

        if not landmarks:
            return None

        return ProcessedSequence(
            frames=np.array(frames),
            landmarks=np.array(landmarks),
            timestamps=np.array(timestamps),
            confidence_scores=np.array(confidence_scores)
        )

    # Example usage
    def analyze_videos(self, reference_path: str, user_path: str) -> dict:
        """
        Analyze two videos and return comparison results.

        Args:
            reference_path: Path to reference video
            user_path: Path to user video
        Returns:
            Dictionary containing analysis results
        """
        # Process both videos
        reference_seq = self.process_video(reference_path)
        user_seq = self.process_video(user_path)

        if reference_seq is None or user_seq is None:
            raise ValueError("Failed to process one or both videos")

        # Compute similarity and get aligned sequences
        overall_similarity, frame_similarities, (aligned_ref, aligned_user) = self.compute_similarity(
            reference_seq, user_seq
        )

        # Generate visualizations using aligned sequences
        visualizations = self.visualize_comparison(
            aligned_ref,
            aligned_user,
            frame_similarities
        )

        return {
        'overall_similarity': overall_similarity,
        'frame_similarities': frame_similarities,
        'visualizations': visualizations,
        'aligned_sequences': (aligned_ref, aligned_user)
        }

    def _extract_keypoints(self, landmarks) -> np.ndarray:
        """Extract relevant keypoints for deadlift analysis."""
        keypoints = []
        for landmark in self.KEY_POINTS:
            point = landmarks.landmark[landmark]
            keypoints.extend([point.x, point.y, point.z])
        return np.array(keypoints)

    def _get_confidence_scores(self, landmarks) -> np.ndarray:
        """Get confidence scores for key points."""
        return np.array([landmarks.landmark[point].visibility for point in self.KEY_POINTS])


    def visualize_comparison(self,
                        seq1: ProcessedSequence,
                        seq2: ProcessedSequence,
                        similarities: np.ndarray,
                        target_height: int = 720) -> List[np.ndarray]:
      """Generate visualization frames comparing two sequences.

      Args:
          seq1: First sequence
          seq2: Second sequence
          similarities: Array of similarity scores
          target_height: Height to resize frames to (default 720p)
      """
      visualizations = []

      for i in range(len(similarities)):
          # Get original frames
          frame1 = seq1.frames[i]
```

```python
      """
      visualizations = []

      for i in range(len(similarities)):
          # Get original frames
          frame1 = seq1.frames[i]
          frame2 = seq2.frames[i]

          # Get original dimensions
          h1, w1 = frame1.shape[:2]
          h2, w2 = frame2.shape[:2]

          # Calculate resize ratios
          ratio1 = target_height / h1
          ratio2 = target_height / h2

          # Resize frames
          frame1 = cv2.resize(frame1, (int(w1 * ratio1), target_height))
          frame2 = cv2.resize(frame2, (int(w2 * ratio2), target_height))

          # Get new dimensions
          h, w1 = frame1.shape[:2]
          _, w2 = frame2.shape[:2]

          # Create side-by-side comparison
          vis_frame = np.hstack([frame1, frame2])

          # Draw landmarks and connections
          for j, landmark in enumerate(self.KEY_POINTS):
              # First frame - adjust coordinates for resized frame
              x1 = int(seq1.landmarks[i][j*3] * w1)
              y1 = int(seq1.landmarks[i][j*3 + 1] * h)
              conf1 = seq1.confidence_scores[i][j]

              # Second frame - adjust coordinates for resized frame
              x2 = int(seq2.landmarks[i][j*3] * w2) + w1  # Offset by first frame width
              y2 = int(seq2.landmarks[i][j*3 + 1] * h)
              conf2 = seq2.confidence_scores[i][j]

              # Draw points and confidence scores
              if conf1 > self.confidence_threshold:
                  cv2.circle(vis_frame, (x1, y1), 5, (0, 255, 0), -1)
                  cv2.putText(vis_frame, f"{conf1:.2f}", (x1, y1-10),
                            cv2.FONT_HERSHEY_SIMPLEX, 0.5, (255, 255, 255), 1)

              if conf2 > self.confidence_threshold:
                  cv2.circle(vis_frame, (x2, y2), 5, (0, 255, 0), -1)
                  cv2.putText(vis_frame, f"{conf2:.2f}", (x2, y2-10),
                            cv2.FONT_HERSHEY_SIMPLEX, 0.5, (255, 255, 255), 1)

          # Add similarity score
          cv2.putText(vis_frame, f"Similarity: {similarities[i]:.3f}", (10, 30),
                    cv2.FONT_HERSHEY_SIMPLEX, 1, (255, 255, 255), 2)

          visualizations.append(vis_frame)

      return visualizations

    def plot_similarity_timeline(self, similarities: np.ndarray) -> None:
        """Plot similarity scores over time."""
        plt.figure(figsize=(12, 4))
        plt.plot(similarities)
        plt.title('Pose Similarity Over Time')
        plt.xlabel('Frame')
        plt.ylabel('Similarity Score')
        plt.grid(True)
        plt.show()
```

```python
[ ] from google.colab.patches import cv2_imshow
```

```python
[ ]
user_dir = "/content/drive/MyDrive/AI in Healthcare/Final Project/data/videos/user/deadlift_incorrect_01.mp4"
reference_dir = "/content/drive/MyDrive/AI in Healthcare/Final Project/data/videos/reference/deadlift_12.mp4"
# Initialize processor
processor = DeadliftProcessor()

# Analyze videos
results = processor.analyze_videos(reference_dir, user_dir)

# Access results
print(f"Overall similarity: {results['overall_similarity']:.3f}")
```

```python
# Analyze videos
[ ] results = processor.analyze_videos(reference_dir, user_dir)

# Access results
print(f"Overall similarity: {results['overall_similarity']:.3f}")

# Display visualization
for frame in results['visualizations']:
    cv2_imshow( frame)
    if cv2.waitKey(30) & 0xFF == ord('q'):
        break
```

Show hidden output

```python
[ ] !pip install opencv-python numpy matplotlib mediapipe google-colab fastdtw scipy
```

Show hidden output

```python
[ ] import cv2
import numpy as np
import mediapipe as mp
import torch
import torch.nn as nn
from torch.utils.data import Dataset, DataLoader
from scipy.signal import find_peaks
from fastdtw import fastdtw
from scipy.spatial.distance import cosine
from dataclasses import dataclass
from typing import List, Tuple, Optional, Dict
from pathlib import Path
import matplotlib.pyplot as plt
```

```python
@dataclass
class ProcessedSequence:
    """Container for processed video sequence data"""
    frames: np.ndarray  # Original video frames
    landmarks: np.ndarray  # Extracted pose landmarks
    timestamps: np.ndarray  # Frame timestamps
    confidence_scores: np.ndarray  # Landmark confidence scores
```

```python
[ ] class RepDetector:
    """Detects deadlift reps using floor-to-standing-to-floor cycle detection"""
    def __init__(self):
        self.mp_pose = mp.solutions.pose
        self.SHOULDER_INDICES = [0, 1]
        # Adjust thresholds for deadlift-specific detection
        self.min_rep_frames = 10
        self.floor_threshold = 0.1  # Threshold to determine "at floor" position
        self.movement_threshold = 0.001  # Minimum movement to consider valid
        self.smooth_window_ratio = 0.1

    def _get_adaptive_parameters(self, sequence_length: int, fps: Optional[float] = None) -> dict:
        """Calculate adaptive parameters based on deadlift-specific durations"""
        if fps is None or fps <= 0:
            fps = 30

        # Typical deadlift rep durations
        min_rep_duration = 2.0  # seconds - faster reps possible in deadlifts
        typical_rep_duration = 4.0  # seconds
        max_rep_duration = 8.0  # seconds

        expected_rep_frames = int(fps * typical_rep_duration)
        min_rep_frames = int(fps * min_rep_duration)
        max_rep_frames = int(fps * max_rep_duration)

        sequence_based_window = int(sequence_length * self.smooth_window_ratio)
        rep_based_window = int(expected_rep_frames * 0.15)  # Reduced window for better sensitivity

        params = {
            'min_frames': min_rep_frames,
            'max_frames': max_rep_frames,
            'smooth_window': max(3, min(sequence_based_window, rep_based_window)),
            'distance': int(fps * 1.0),  # Reduced minimum distance between reps
        }

        if params['smooth_window'] % 2 == 0:
            params['smooth_window'] += 1

        return params
```

Demo
(Code)

```python
        return params

    def _detect_floor_positions(self, smoothed: np.ndarray, slopes: np.ndarray) -> List[int]:
        """Detect positions where the lifter is at the floor position"""
        # Find local minima (floor positions)
        floor_positions = []

        for i in range(1, len(smoothed) - 1):
            # Check if it's a local minimum
            if (smoothed[i] <= smoothed[i-1] and
                smoothed[i] <= smoothed[i+1] and
                abs(slopes[i]) < self.floor_threshold):

                # Verify it's close to the global minimum (floor position)
                local_min = smoothed[i]
                global_min = np.min(smoothed)
                if abs(local_min - global_min) < self.floor_threshold * 2:
                    floor_positions.append(i)

        return floor_positions

    def _detect_standing_positions(self, smoothed: np.ndarray, slopes: np.ndarray,
                                   floor_positions: List[int]) -> List[int]:
        """Detect positions where the lifter is in the standing position"""
        standing_positions = []

        for i in range(1, len(floor_positions)):
            start = floor_positions[i-1]
            end = floor_positions[i]

            # Find the highest point between floor positions
            section = smoothed[start:end]
            relative_max_idx = np.argmax(section)
            max_idx = start + relative_max_idx

            # Verify it's a valid standing position
            if (abs(slopes[max_idx]) < self.floor_threshold and  # Nearly zero slope
                smoothed[max_idx] - smoothed[start] > self.movement_threshold):  # Significant height difference
                standing_positions.append(max_idx)

        return standing_positions

    def detect_reps(self, sequence: ProcessedSequence) -> List[Tuple[int, int]]:
        """Detect deadlift reps using floor-to-standing-to-floor cycle detection"""
        if len(sequence.landmarks) == 0:
            return []

        # Process shoulder height data
        shoulder_heights = []
        for landmarks in sequence.landmarks:
            shoulder_y_coords = [landmarks[idx * 3 + 1] for idx in self.SHOULDER_INDICES]
            shoulder_heights.append(np.mean(shoulder_y_coords))

        shoulder_heights = np.array(shoulder_heights)
        fps = len(sequence.timestamps) / ((sequence.timestamps[-1] - sequence.timestamps[0]) / 1000)
        params = self._get_adaptive_parameters(len(shoulder_heights), fps)

        # Smooth signal and calculate slopes
        smoothed = self._smooth_signal(shoulder_heights, params['smooth_window'])
        slopes = np.gradient(smoothed)

        # Detect floor and standing positions
        floor_positions = self._detect_floor_positions(smoothed, slopes)
        standing_positions = self._detect_standing_positions(smoothed, slopes, floor_positions)

        # Validate and combine into reps
        reps = []
        for i in range(len(floor_positions) - 1):
            start_idx = floor_positions[i]
            end_idx = floor_positions[i + 1]

            # Find standing position between these floor positions
            standing_between = [pos for pos in standing_positions
                                if start_idx < pos < end_idx]

            if standing_between:  # Valid rep must have a standing position
                rep_duration = end_idx - start_idx

                # Duration validation
                if (params['min_frames'] <= rep_duration <= params['max_frames']):
                    # Verify minimum movement threshold
```

```python
                # Duration validation
                if (params['min_frames'] <= rep_duration <= params['max_frames']):
                    # Verify minimum movement threshold
                    section = smoothed[start_idx:end_idx]
                    height_difference = np.max(section) - np.min(section)

                    if height_difference > self.movement_threshold:
                        reps.append((start_idx, end_idx))

        # Visualization for debugging
        print("VISUALIZING REPS-----")
        self._visualize_reps(smoothed, floor_positions, standing_positions, slopes, reps)

        return reps

    def _visualize_reps(self, smoothed, floor_positions, standing_positions, slopes, reps):
        """Visualize the deadlift detection results"""
        plt.figure(figsize=(15, 8))

        # Plot main signal
        plt.subplot(211)
        plt.plot(smoothed, label='Smoothed Signal')
        plt.plot(floor_positions, smoothed[floor_positions], "x", label='Floor Positions')
        plt.plot(standing_positions, smoothed[standing_positions], "o", label='Standing Positions')

        for start, end in reps:
            plt.axvspan(start, end, alpha=0.2, color='green',
                        label='Detected Rep' if start == reps[0][0] else None)

        plt.legend()
        plt.title('Deadlift Rep Detection')

        # Plot slopes
        plt.subplot(212)
        plt.plot(slopes, label='Slope')
        plt.plot(floor_positions, slopes[floor_positions], "x", label='Floor Positions')
        plt.plot(standing_positions, slopes[standing_positions], "o", label='Standing Positions')

        plt.axhline(y=0, color='r', linestyle='--', alpha=0.3)
        plt.axhline(y=self.floor_threshold, color='g', linestyle='--', alpha=0.3, label='Floor Threshold')
        plt.axhline(y=-self.floor_threshold, color='g', linestyle='--', alpha=0.3)

        plt.legend()
        plt.title('Slope Analysis')

        plt.tight_layout()
        plt.show()

    def _smooth_signal(self, signal: np.ndarray, window_size: int) -> np.ndarray:
        """Apply Gaussian smoothing to the signal"""
        from scipy.ndimage import gaussian_filter1d
        sigma = window_size / 6.0
        return gaussian_filter1d(signal, sigma)

    def extract_rep(self, sequence: ProcessedSequence, start_idx: int, end_idx: int) -> ProcessedSequence:
        """Extract a single rep from the sequence"""
        return ProcessedSequence(
            frames=sequence.frames[start_idx:end_idx],
            landmarks=sequence.landmarks[start_idx:end_idx],
            timestamps=sequence.timestamps[start_idx:end_idx],
            confidence_scores=sequence.confidence_scores[start_idx:end_idx]
        )
```

```python
[ ] class DeadliftDataset(Dataset):
        """Dataset for training the form scoring model with fixed-length sequences"""
        def __init__(self, processor: 'DeadliftProcessor',
                     reference_videos: List[str],
                     training_videos: List[str],
                     target_length: int = 32):
          self.sequences = []
          self.scores = []
          self.target_length = target_length

          print(f"Processing {len(reference_videos)} reference videos and {len(training_videos)} training videos")

          # Process reference videos
          reference_reps = []
          for ref_path in reference_videos:
              seq = processor.process_video(ref_path)
              if seq is not None:
                  reps = processor.rep_detector.detect_reps(seq)
```

```python
              if seq is not None:
                  reps = processor.rep_detector.detect_reps(seq)
                  if reps:
                      mid_rep = reps[len(reps)//2]
                      ref_rep = processor.rep_detector.extract_rep(seq, *mid_rep)

                      reference_reps.append({
                          'landmarks': ref_rep.landmarks,  # Store original sequences
                          'confidence_scores': ref_rep.confidence_scores
                      })
              del seq

          # Process training videos
          for video_path in training_videos:
              seq = processor.process_video(video_path)
              if seq is not None:
                  reps = processor.rep_detector.detect_reps(seq)
                  if reps:
                      for rep_start, rep_end in reps:
                          train_rep = processor.rep_detector.extract_rep(seq, rep_start, rep_end)

                          # Compute DTW similarity with each reference
                          rep_scores = []
                          for ref in reference_reps:
                              similarity = self._compute_dtw_similarity(
                                  ref['landmarks'],
                                  train_rep.landmarks,
                                  ref['confidence_scores'],
                                  train_rep.confidence_scores
                              )
                              rep_scores.append(similarity)

                          # Store normalized sequence for the model
                          normalized_landmarks = self._interpolate_sequence(train_rep.landmarks)
                          normalized_confidence = self._interpolate_sequence(train_rep.confidence_scores)

                          self.sequences.append({
                              'landmarks': normalized_landmarks,
                              'confidence_scores': normalized_confidence
                          })
                          self.scores.append(np.mean(rep_scores))
              del seq

        def _interpolate_sequence(self, sequence: np.ndarray) -> np.ndarray:
            """Interpolate a sequence to target length"""
            # Create time points for interpolation
            original_time = np.linspace(0, 1, len(sequence))
            target_time = np.linspace(0, 1, self.target_length)

            # Initialize output array
            interpolated = np.zeros((self.target_length, sequence.shape[1]))

            # Interpolate each feature independently
            for i in range(sequence.shape[1]):
                interpolated[:, i] = np.interp(target_time, original_time, sequence[:, i])

            return interpolated

        def _compute_dtw_similarity(self, seq1_landmarks: np.ndarray, seq2_landmarks: np.ndarray,
                                    seq1_confidence: np.ndarray, seq2_confidence: np.ndarray) -> float:
          """
          Compute DTW-based similarity between two sequences without prior normalization
          """
          # Compute DTW path
          distance, path = fastdtw(seq1_landmarks, seq2_landmarks,
                                   dist=lambda x, y: np.linalg.norm(x - y))
          path = np.array(path)

          # Create aligned sequences using the DTW path
          aligned_seq1_landmarks = seq1_landmarks[path[:, 0]]
          aligned_seq2_landmarks = seq2_landmarks[path[:, 1]]
          aligned_seq1_conf = seq1_confidence[path[:, 0]]
          aligned_seq2_conf = seq2_confidence[path[:, 1]]

          # Compute frame-by-frame similarities
          similarities = []
          for i in range(len(aligned_seq1_landmarks)):
              # Combine confidence scores
              weights = aligned_seq1_conf[i] * aligned_seq2_conf[i]
              weights = weights / (np.sum(weights) + 1e-6)

              # Weight the landmarks
              weighted_landmarks1 = aligned_seq1_landmarks[i] * np.repeat(weights, 3)
```

Demo
(Code)

```python
        similarities = []
[ ]     for i in range(len(aligned_seq1_landmarks)):
            # Combine confidence scores
            weights = aligned_seq1_conf[i] * aligned_seq2_conf[i]
            weights = weights / (np.sum(weights) + 1e-6)

            # Weight the landmarks
            weighted_landmarks1 = aligned_seq1_landmarks[i] * np.repeat(weights, 3)
            weighted_landmarks2 = aligned_seq2_landmarks[i] * np.repeat(weights, 3)

            # Compute similarity
            sim = 1 - cosine(weighted_landmarks1, weighted_landmarks2)
            similarities.append(sim)

        return np.mean(similarities)

    def __len__(self):
        return len(self.sequences)

    def __getitem__(self, idx):
        sequence = torch.tensor(self.sequences[idx]['landmarks'], dtype=torch.float32)
        confidence = torch.tensor(self.sequences[idx]['confidence_scores'], dtype=torch.float32)
        score = torch.tensor(self.scores[idx], dtype=torch.float32)
        return sequence, confidence, score
```

```python
class DeadliftScorer(nn.Module):
    """Neural network for scoring deadlift form with fixed attention dimensions"""
    def __init__(self, input_size: int, hidden_size: int = 64):
        super().__init__()
        self.lstm = nn.LSTM(input_size, hidden_size, batch_first=True, bidirectional=True)

        # Adjust attention mechanism
        self.attention_dim = 2 * hidden_size  # bidirectional LSTM output size
        self.attention = nn.MultiheadAttention(
            embed_dim=self.attention_dim,
            num_heads=4,
            batch_first=True  # Important: use batch_first=True
        )

        # Scoring layers
        self.frame_scorer = nn.Sequential(  # Changed back to frame_scorer
            nn.Linear(self.attention_dim, hidden_size),
            nn.ReLU(),
            nn.Dropout(0.2),
            nn.Linear(hidden_size, 1),
            nn.Sigmoid()
        )


        # Global average pooling for final score
        self.global_pool = nn.AdaptiveAvgPool1d(1)

    def get_frame_scores(self, x: torch.Tensor, confidence: torch.Tensor) -> torch.Tensor:
        """Get frame-by-frame scores before pooling"""
        # Compute average confidence per frame
        avg_confidence = confidence.mean(dim=-1, keepdim=True)

        # Apply confidence weighting
        x = x * avg_confidence

        # Process sequence
        lstm_out, _ = self.lstm(x)

        # Prepare for attention
        lstm_out = lstm_out.transpose(0, 1)
        attn_out, _ = self.attention(lstm_out, lstm_out, lstm_out)
        attn_out = attn_out.transpose(0, 1)

        # Generate frame-by-frame scores
        frame_scores = self.frame_scorer(attn_out).squeeze(-1)

        return frame_scores

    def forward(self, x: torch.Tensor, confidence: torch.Tensor) -> torch.Tensor:
        """Forward pass returning single score per sequence"""
        frame_scores = self.get_frame_scores(x, confidence)
        return self.global_pool(frame_scores.unsqueeze(1)).squeeze()
```

```python
[ ] class DeadliftProcessor:
        def __init__(self, confidence_threshold: float = 0.3):
            self.mp_pose = mp.solutions.pose
```

```python
class DeadliftProcessor:
    def __init__(self, confidence_threshold: float = 0.3):
        self.mp_pose = mp.solutions.pose
        self.pose = self.mp_pose.Pose(
            static_image_mode=False,
            min_detection_confidence=0.7,
            model_complexity=1
        )
        self.confidence_threshold = confidence_threshold
        self.rep_detector = RepDetector()

        # Key points for deadlift form
        self.KEY_POINTS = [
            self.mp_pose.PoseLandmark.LEFT_SHOULDER,
            self.mp_pose.PoseLandmark.RIGHT_SHOULDER,
            self.mp_pose.PoseLandmark.LEFT_HIP,
            self.mp_pose.PoseLandmark.RIGHT_HIP,
            self.mp_pose.PoseLandmark.LEFT_KNEE,
            self.mp_pose.PoseLandmark.RIGHT_KNEE,
            self.mp_pose.PoseLandmark.LEFT_ANKLE,
            self.mp_pose.PoseLandmark.RIGHT_ANKLE
        ]

    def process_video(self, video_path: str) -> Optional[ProcessedSequence]:
        """Process video and extract pose sequences"""
        cap = cv2.VideoCapture(video_path)
        if not cap.isOpened():
            raise ValueError(f"Could not open video file: {video_path}")

        frames = []
        landmarks = []
        timestamps = []
        confidence_scores = []

        frame_count = 0
        fps = cap.get(cv2.CAP_PROP_FPS)

        while cap.isOpened():
            ret, frame = cap.read()
            if not ret:
                break

            timestamp = (frame_count / fps) * 1000
            frame_count += 1

            frame_rgb = cv2.cvtColor(frame, cv2.COLOR_BGR2RGB)
            results = self.pose.process(frame_rgb)

            if results.pose_landmarks:
                frame_landmarks = self._extract_keypoints(results.pose_landmarks)
                frame_confidence = self._get_confidence_scores(results.pose_landmarks)

                if np.mean(frame_confidence) > self.confidence_threshold:
                    frames.append(frame)
                    landmarks.append(frame_landmarks)
                    timestamps.append(timestamp)
                    confidence_scores.append(frame_confidence)

        cap.release()

        if not landmarks:
            return None

        return ProcessedSequence(
            frames=np.array(frames),
            landmarks=np.array(landmarks),
            timestamps=np.array(timestamps),
            confidence_scores=np.array(confidence_scores)
        )

    def compute_similarity(self, seq1: ProcessedSequence, seq2: ProcessedSequence) -> Tuple[float, np.ndarray, Tuple[ProcessedSequence, ProcessedSequence]]:
        """Compute similarity between two sequences using DTW"""
        # Compute DTW path
        distance, path = fastdtw(seq1.landmarks, seq2.landmarks, dist=lambda x, y: np.linalg.norm(x - y))
        path = np.array(path)

        # Create aligned sequences
        aligned_seq1 = ProcessedSequence(
            frames=seq1.frames[path[:, 0]],
            landmarks=seq1.landmarks[path[:, 0]],
            timestamps=seq1.timestamps[path[:, 0]],
```

```python
        )

        aligned_seq2 = ProcessedSequence(
            frames=seq2.frames[path[:, 1]],
            landmarks=seq2.landmarks[path[:, 1]],
            timestamps=seq2.timestamps[path[:, 1]],
            confidence_scores=seq2.confidence_scores[path[:, 1]]
        )

        # Compute frame similarities
        frame_similarities = []
        for i in range(len(aligned_seq1.landmarks)):
            weights = aligned_seq1.confidence_scores[i] * aligned_seq2.confidence_scores[i]
            weights = weights / (np.sum(weights) + 1e-6)

            weighted_landmarks1 = aligned_seq1.landmarks[i] * np.repeat(weights, 3)
            weighted_landmarks2 = aligned_seq2.landmarks[i] * np.repeat(weights, 3)

            sim = 1 - cosine(weighted_landmarks1, weighted_landmarks2)
            frame_similarities.append(sim)

        return np.mean(frame_similarities), np.array(frame_similarities), (aligned_seq1, aligned_seq2)

    def _extract_keypoints(self, landmarks) -> np.ndarray:
        """Extract relevant keypoints for deadlift analysis"""
        keypoints = []
        for landmark in self.KEY_POINTS:
            point = landmarks.landmark[landmark]
            keypoints.extend([point.x, point.y, point.z])
        return np.array(keypoints)

    def _get_confidence_scores(self, landmarks) -> np.ndarray:
        """Get confidence scores for key points"""
        return np.array([landmarks.landmark[point].visibility for point in self.KEY_POINTS])

    def visualize_comparison(self, seq1: ProcessedSequence, seq2: ProcessedSequence,
                             similarities: np.ndarray, target_height: int = 720) -> List[np.ndarray]:
        """Generate visualization frames comparing two sequences"""
        visualizations = []

        for i in range(len(similarities)):
            frame1 = seq1.frames[i]
            frame2 = seq2.frames[i]

            h1, w1 = frame1.shape[:2]
            h2, w2 = frame2.shape[:2]

            ratio1 = target_height / h1
            ratio2 = target_height / h2

            frame1 = cv2.resize(frame1, (int(w1 * ratio1), target_height))
            frame2 = cv2.resize(frame2, (int(w2 * ratio2), target_height))

            h, w1 = frame1.shape[:2]
            _, w2 = frame2.shape[:2]

            vis_frame = np.hstack([frame1, frame2])

            # Draw landmarks
            for j, landmark in enumerate(self.KEY_POINTS):
                # First frame
                x1 = int(seq1.landmarks[i][j*3] * w1)
                y1 = int(seq1.landmarks[i][j*3 + 1] * h)
                conf1 = seq1.confidence_scores[i][j]

                # Second frame
                x2 = int(seq2.landmarks[i][j*3] * w2) + w1
                y2 = int(seq2.landmarks[i][j*3 + 1] * h)
                conf2 = seq2.confidence_scores[i][j]

                if conf1 > self.confidence_threshold:
                    cv2.circle(vis_frame, (x1, y1), 5, (0, 255, 0), -1)

                if conf2 > self.confidence_threshold:
                    cv2.circle(vis_frame, (x2, y2), 5, (0, 255, 0), -1)

            cv2.putText(vis_frame, f"Similarity: {similarities[i]:.3f}", (10, 30),
                        cv2.FONT_HERSHEY_SIMPLEX, 1, (255, 255, 255), 2)

            visualizations.append(vis_frame)

        return visualizations
```

Demo
(Code)

```python
        return visualizations

    def analyze_single_rep(self, reference_path: str, user_path: str) -> dict:
        """Analyze a single rep from each video"""
        # Process videos
        ref_seq = self.process_video(reference_path)
        user_seq = self.process_video(user_path)

        if ref_seq is None or user_seq is None:
            raise ValueError("Failed to process one or both videos")

        # Detect reps
        ref_reps = self.rep_detector.detect_reps(ref_seq)
        user_reps = self.rep_detector.detect_reps(user_seq)

        if not ref_reps or not user_reps:
            raise ValueError("No complete reps detected")

        # Extract middle rep from each sequence
        ref_rep_idx = len(ref_reps) // 2
        user_rep_idx = len(user_reps) // 2

        ref_single_rep = self.rep_detector.extract_rep(
            ref_seq,
            ref_reps[ref_rep_idx][0],
            ref_reps[ref_rep_idx][1]
        )

        user_single_rep = self.rep_detector.extract_rep(
            user_seq,
            user_reps[user_rep_idx][0],
            user_reps[user_rep_idx][1]
        )

        # Compute similarity
        overall_similarity, frame_similarities, (aligned_ref, aligned_user) = self.compute_similarity(
            ref_single_rep, user_single_rep
        )

        return {
            'overall_similarity': overall_similarity,
            'frame_similarities': frame_similarities,
            'visualizations': self.visualize_comparison(
                aligned_ref,
                aligned_user,
                frame_similarities
            ),
            'aligned_sequences': (aligned_ref, aligned_user),
            'ref_rep': ref_single_rep,
            'user_rep': user_single_rep
        }
```

```python
class DeadliftFormTrainer:
    """Handles training and prediction for the form scoring model"""
    def __init__(self, processor: DeadliftProcessor):
        self.processor = processor
        self.model = None
        self.device = torch.device("cuda" if torch.cuda.is_available() else "cpu")
        self.target_length = 32  # Default sequence length

    def prepare_dataset(self, reference_dir: str, training_dir: str) -> DeadliftDataset:
        """Prepare dataset from directories"""
        reference_videos = list(Path(reference_dir).glob("*.mp4"))
        training_videos = list(Path(training_dir).glob("*.mp4"))

        print(f"Processing {len(reference_videos)} reference videos and {len(training_videos)} training videos")

        return DeadliftDataset(
            self.processor,
            [str(p) for p in reference_videos],
            [str(p) for p in training_videos]
        )

    def _normalize_sequence(self, sequence: np.ndarray) -> np.ndarray:
        """Interpolate sequence to target length"""
        original_time = np.linspace(0, 1, len(sequence))
        target_time = np.linspace(0, 1, self.target_length)

        interpolated = np.zeros((self.target_length, sequence.shape[1]))
        for i in range(sequence.shape[1]):
```

```python
    def _normalize_sequence(self, sequence: np.ndarray) -> np.ndarray:
        """Interpolate sequence to target length"""
        original_time = np.linspace(0, 1, len(sequence))
        target_time = np.linspace(0, 1, self.target_length)

        interpolated = np.zeros((self.target_length, sequence.shape[1]))
        for i in range(sequence.shape[1]):
            interpolated[:, i] = np.interp(target_time, original_time, sequence[:, i])

        return interpolated

    def train(self, dataset: DeadliftDataset,
              epochs: int = 50, batch_size: int = 16, learning_rate: float = 0.001):
        """Train the scoring model"""
        input_size = dataset[0][0].shape[-1]  # Landmark feature dimension
        self.model = DeadliftScorer(input_size).to(self.device)

        # Split dataset
        train_size = int(0.8 * len(dataset))
        val_size = len(dataset) - train_size
        train_dataset, val_dataset = torch.utils.data.random_split(dataset, [train_size, val_size])

        train_loader = DataLoader(train_dataset, batch_size=batch_size, shuffle=True)
        val_loader = DataLoader(val_dataset, batch_size=batch_size)

        criterion = nn.MSELoss()
        optimizer = torch.optim.Adam(self.model.parameters(), lr=learning_rate)
        scheduler = torch.optim.lr_scheduler.ReduceLROnPlateau(optimizer, 'min', patience=5)

        best_val_loss = float('inf')

        for epoch in range(epochs):
            # Training
            self.model.train()
            train_loss = 0
            for sequences, confidence, target_scores in train_loader:
                sequences = sequences.to(self.device)
                confidence = confidence.to(self.device)
                target_scores = target_scores.to(self.device)

                optimizer.zero_grad()
                predicted_scores = self.model(sequences, confidence)
                loss = criterion(predicted_scores, target_scores)
                loss.backward()
                optimizer.step()

                train_loss += loss.item()

            # Validation
            self.model.eval()
            val_loss = 0
            with torch.no_grad():
                for sequences, confidence, target_scores in val_loader:
                    sequences = sequences.to(self.device)
                    confidence = confidence.to(self.device)
                    target_scores = target_scores.to(self.device)

                    predicted_scores = self.model(sequences, confidence)
                    val_loss += criterion(predicted_scores, target_scores).item()

            avg_val_loss = val_loss / len(val_loader)
            scheduler.step(avg_val_loss)

            print(f"Epoch {epoch+1}/{epochs}")
            print(f"Training Loss: {train_loss/len(train_loader):.4f}")
            print(f"Validation Loss: {avg_val_loss:.4f}")

            if avg_val_loss < best_val_loss:
                best_val_loss = avg_val_loss
                torch.save(self.model.state_dict(), 'best_model.pth')

    def visualize_scored_rep(self, sequence: ProcessedSequence, scores: np.ndarray, target_height: int = 720) -> List[np.ndarray]:
        """Generate visualization frames with score overlays"""
        visualizations = []

        # Interpolate scores to match sequence length if needed
        if len(scores) != len(sequence.frames):
            time_orig = np.linspace(0, 1, len(scores))
            time_new = np.linspace(0, 1, len(sequence.frames))
            scores = np.interp(time_new, time_orig, scores)

        for i in range(len(sequence.frames)):
```

```python
        for i in range(len(sequence.frames)):
            frame = sequence.frames[i]
            score = scores[i]

            # Resize frame
            h, w = frame.shape[:2]
            ratio = target_height / h
            frame = cv2.resize(frame, (int(w * ratio), target_height))

            # Draw landmarks
            for j, landmark in enumerate(self.processor.KEY_POINTS):
                x = int(sequence.landmarks[i][j*3] * frame.shape[1])
                y = int(sequence.landmarks[i][j*3 + 1] * frame.shape[0])
                conf = sequence.confidence_scores[i][j]

                if conf > self.processor.confidence_threshold:
                    # Color code points based on score (red->yellow->green)
                    color = (
                        0,  # Blue
                        int(255 * score),  # Green
                        int(255 * (1 - score))  # Red
                    )
                    cv2.circle(frame, (x, y), 5, color, -1)

            # Add score overlay with solid background box
            text = f"Frame Score: {score:.3f}"
            font = cv2.FONT_HERSHEY_SIMPLEX
            font_scale = 1
            thickness = 2

            # Get text size
            (text_width, text_height), baseline = cv2.getTextSize(text, font, font_scale, thickness)

            # Calculate box coordinates
            box_padding = 10
            box_x = 10
            box_y = 10
            box_width = text_width + 2 * box_padding
            box_height = text_height + 2 * box_padding

            # Draw solid black background box
            cv2.rectangle(frame,
                          (box_x, box_y),
                          (box_x + box_width, box_y + box_height),
                          (0, 0, 0),
                          -1)

            # Draw text
            text_x = box_x + box_padding
            text_y = box_y + box_height - box_padding
            cv2.putText(
                frame,
                text,
                (text_x, text_y),
                font,
                font_scale,
                (255, 255, 255),
                thickness
            )

            visualizations.append(frame)

        return visualizations

    def predict(self, video_path: str) -> Dict:
        """Predict form scores for a new video with visualization"""
        if self.model is None:
            raise ValueError("Model must be trained before prediction")

        sequence = self.processor.process_video(video_path)
        if sequence is None:
            raise ValueError("Failed to process video")

        reps = self.processor.rep_detector.detect_reps(sequence)
        if not reps:
            raise ValueError("No complete reps detected")

        rep_scores = []
        rep_sequences = []
        rep_visualizations = []

        # Score each rep
```

Demo
(Code)

```python
        # Score each rep
        for rep_start, rep_end in reps:
            rep_seq = self.processor.rep_detector.extract_rep(
                sequence, rep_start, rep_end
            )

            # Normalize sequence length
            normalized_landmarks = torch.tensor(
                self._normalize_sequence(rep_seq.landmarks),
                dtype=torch.float32
            ).unsqueeze(0)
            normalized_confidence = torch.tensor(
                self._normalize_sequence(rep_seq.confidence_scores),
                dtype=torch.float32
            ).unsqueeze(0)

            self.model.eval()
            with torch.no_grad():
                normalized_landmarks = normalized_landmarks.to(self.device)
                normalized_confidence = normalized_confidence.to(self.device)

                # Get frame-by-frame scores
                scores = self.model.get_frame_scores(normalized_landmarks, normalized_confidence)
                scores = scores.cpu().numpy()[0]

                # Generate visualization
                vis_frames = self.visualize_scored_rep(rep_seq, scores)

                rep_scores.append(scores)
                rep_sequences.append(rep_seq)
                rep_visualizations.append(vis_frames)

        return {
            'rep_scores': rep_scores,
            'rep_sequences': rep_sequences,
            'rep_visualizations': rep_visualizations,
            'overall_score': np.mean([np.mean(scores) for scores in rep_scores])
        }
```

```python
from google.colab.patches import cv2_imshow
```

```python
import time
from IPython.display import clear_output

def display_sequence_comparison(reference_path: str, user_path: str,
                                frame_delay: float = 0.1):
    """
    Display sequence comparison with proper frame timing in Colab.

    Args:
        reference_path: Path to reference video
        user_path: Path to user video
        frame_delay: Delay between frames in seconds
    """
    # Initialize processor
    processor = DeadliftProcessor()

    # Process videos
    reference_seq = processor.process_video(reference_path)
    user_seq = processor.process_video(user_path)

    if reference_seq and user_seq:
        # Compute similarity and align sequences
        overall_similarity, frame_similarities, (aligned_ref, aligned_user) = processor.compute_similarity(
            reference_seq, user_seq
        )

        print(f"Overall Similarity Score: {overall_similarity:.3f}")
        print(f"Number of aligned frames: {len(frame_similarities)}")

        # Visualize comparison
        visualizations = processor.visualize_comparison(
            aligned_ref, aligned_user, frame_similarities
        )

        # Display visualizations with proper timing
        for i, frame in enumerate(visualizations):
            clear_output(wait=True)  # Clear previous frame
            cv2_imshow(frame)
            print(f"Frame {i+1}/{len(visualizations)} - Similarity: {frame_similarities[i]:.3f}")
            time.sleep(frame_delay)  # Add delay between frames
```

```python
        # Display visualizations with proper timing
        for i, frame in enumerate(visualizations):
            clear_output(wait=True)  # Clear previous frame
            cv2_imshow(frame)
            print(f"Frame {i+1}/{len(visualizations)} - Similarity: {frame_similarities[i]:.3f}")
            time.sleep(frame_delay)  # Add delay between frames

        # Display final summary
        print("\nVisualization Complete")
        print(f"Final Overall Similarity: {overall_similarity:.3f}")
        print(f"Min Frame Similarity: {min(frame_similarities):.3f}")
        print(f"Max Frame Similarity: {max(frame_similarities):.3f}")
    else:
        print("Failed to process one or both videos.")

# Use the function
display_sequence_comparison(reference_path, user_path, frame_delay=0.2)
```

Show hidden output

```python
trainer = DeadliftFormTrainer(processor)
# For training the scoring model
reference_dir = "/content/drive/MyDrive/AI in Healthcare/Final Project/data/videos/reference"
training_dir = "/content/drive/MyDrive/AI in Healthcare/Final Project/data/videos/training"
dataset = trainer.prepare_dataset(reference_dir,training_dir)
```

Show hidden output

```python
class ShoulderVisualizer:
    def __init__(self, dataset: DeadliftDataset):
        self.dataset = dataset
        # Indices for left and right shoulders (x,y,z for each)
        self.left_shoulder_idx = 0  # 0,1,2 for x,y,z
        self.right_shoulder_idx = 1  # 3,4,5 for x,y,z

    def plot_all_shoulder_trajectories(self):
        """Plot shoulder trajectories for all sequences with their scores"""
        n_sequences = len(self.dataset.sequences)
        scores = np.array(self.dataset.scores)

        # Create figure with subplots for x and y coordinates
        fig, (ax1, ax2) = plt.subplots(2, 1, figsize=(15, 12))

        # Color map based on scores
        norm = plt.Normalize(min(scores), max(scores))
        cmap = plt.cm.viridis

        # Plot X coordinates
        ax1.set_title('Shoulder X Coordinates Over Time (All Sequences)')
        for i in range(n_sequences):
            sequence = self.dataset.sequences[i]
            landmarks = sequence['landmarks']
            color = cmap(norm(scores[i]))

            # Plot left and right shoulder X coordinates
            left_x = landmarks[:, self.left_shoulder_idx * 3]
            right_x = landmarks[:, self.right_shoulder_idx * 3]

            # Plot with low alpha for individual sequences
            ax1.plot(left_x, color=color, alpha=0.1, label='_nolegend_')
            ax1.plot(right_x, color=color, alpha=0.1, label='_nolegend_')

        # Add colorbar for scores
        sm1 = plt.cm.ScalarMappable(cmap=cmap, norm=norm)
        plt.colorbar(sm1, ax=ax1, label='Sequence Score')
        ax1.set_xlabel('Frame')
        ax1.set_ylabel('X Coordinate')
        ax1.grid(True, alpha=0.3)

        # Plot Y coordinates
        ax2.set_title('Shoulder Y Coordinates Over Time (All Sequences)')
        for i in range(n_sequences):
            sequence = self.dataset.sequences[i]
            landmarks = sequence['landmarks']
            color = cmap(norm(scores[i]))

            # Plot left and right shoulder Y coordinates
            left_y = landmarks[:, self.left_shoulder_idx * 3 + 1]
            right_y = landmarks[:, self.right_shoulder_idx * 3 + 1]

            # Plot with low alpha for individual sequences
```

```python
            # Plot left and right shoulder Y coordinates
            left_y = landmarks[:, self.left_shoulder_idx * 3 + 1]
            right_y = landmarks[:, self.right_shoulder_idx * 3 + 1]

            # Plot with low alpha for individual sequences
            ax2.plot(left_y, color=color, alpha=0.1, label='_nolegend_')
            ax2.plot(right_y, color=color, alpha=0.1, label='_nolegend_')

        # Add colorbar for scores
        sm2 = plt.cm.ScalarMappable(cmap=cmap, norm=norm)
        plt.colorbar(sm2, ax=ax2, label='Sequence Score')
        ax2.set_xlabel('Frame')
        ax2.set_ylabel('Y Coordinate')
        ax2.grid(True, alpha=0.3)

        plt.tight_layout()
        plt.show()

    def plot_shoulder_statistics(self):
        """Plot statistical summary of shoulder movements"""
        n_sequences = len(self.dataset.sequences)
        n_frames = self.dataset.sequences[0]['landmarks'].shape[0]

        # Initialize arrays for statistics
        left_x_stats = np.zeros((n_frames, 3))  # mean, min, max
        right_x_stats = np.zeros((n_frames, 3))
        left_y_stats = np.zeros((n_frames, 3))
        right_y_stats = np.zeros((n_frames, 3))

        # Collect data for each frame
        for frame in range(n_frames):
            # Left shoulder
            left_x_values = [self.dataset.sequences[i]['landmarks'][frame, self.left_shoulder_idx * 3]
                             for i in range(n_sequences)]
            left_y_values = [self.dataset.sequences[i]['landmarks'][frame, self.left_shoulder_idx * 3 + 1]
                             for i in range(n_sequences)]

            # Right shoulder
            right_x_values = [self.dataset.sequences[i]['landmarks'][frame, self.right_shoulder_idx * 3]
                              for i in range(n_sequences)]
            right_y_values = [self.dataset.sequences[i]['landmarks'][frame, self.right_shoulder_idx * 3 + 1]
                              for i in range(n_sequences)]

            # Calculate statistics
            for values, stats in [(left_x_values, left_x_stats),
                                  (right_x_values, right_x_stats),
                                  (left_y_values, left_y_stats),
                                  (right_y_values, right_y_stats)]:
                stats[frame] = [np.mean(values), np.min(values), np.max(values)]

        # Plot statistics
        fig, (ax1, ax2) = plt.subplots(2, 1, figsize=(15, 12))

        # X coordinates
        ax1.set_title('Statistical Summary of Shoulder X Coordinates')
        ax1.fill_between(range(n_frames), left_x_stats[:, 1], left_x_stats[:, 2],
                         alpha=0.2, label='Left Shoulder Range')
        ax1.plot(left_x_stats[:, 0], label='Left Shoulder Mean', linewidth=2)
        ax1.fill_between(range(n_frames), right_x_stats[:, 1], right_x_stats[:, 2],
                         alpha=0.2, label='Right Shoulder Range')
        ax1.plot(right_x_stats[:, 0], label='Right Shoulder Mean', linewidth=2)
        ax1.set_xlabel('Frame')
        ax1.set_ylabel('X Coordinate')
        ax1.legend()
        ax1.grid(True, alpha=0.3)

        # Y coordinates
        ax2.set_title('Statistical Summary of Shoulder Y Coordinates')
        ax2.fill_between(range(n_frames), left_y_stats[:, 1], left_y_stats[:, 2],
                         alpha=0.2, label='Left Shoulder Range')
        ax2.plot(left_y_stats[:, 0], label='Left Shoulder Mean', linewidth=2)
        ax2.fill_between(range(n_frames), right_y_stats[:, 1], right_y_stats[:, 2],
                         alpha=0.2, label='Right Shoulder Range')
        ax2.plot(right_y_stats[:, 0], label='Right Shoulder Mean', linewidth=2)
        ax2.set_xlabel('Frame')
        ax2.set_ylabel('Y Coordinate')
        ax2.legend()
        ax2.grid(True, alpha=0.3)

        plt.tight_layout()
        plt.show()
```

Demo
(Code)

```
[ ]         plt.tight_layout()
            plt.show()

    # Usage example
    visualizer = ShoulderVisualizer(dataset)

    # Plot all sequences with color-coded scores
    visualizer.plot_all_shoulder_trajectories()

    # Plot statistical summary
    visualizer.plot_shoulder_statistics()
```

Show hidden output

```
[ ] trainer.train(dataset)
```

```
[ ] test_dir="/content/drive/MyDrive/AI in Healthcare/Final Project/data/videos/test/test_03.mp4"
    predictions = trainer.predict(test_dir)
```

Show hidden output

```
# Display visualization for each rep
for rep_idx, vis_frames in enumerate(predictions['rep_visualizations']):
    print(f"\nDisplaying Rep {rep_idx + 1}")
    print(f"Average Score: {np.mean(predictions['rep_scores'][rep_idx]):.3f}")

    # Show every 10th frame
    for i in range(0, len(vis_frames), 10):
        cv2_imshow(vis_frames[i])
        if cv2.waitKey(30) & 0xFF == ord('q'):
            break
```

Show hidden output

Load Model From PTH File

```
[ ] !pip install opencv-python numpy matplotlib mediapipe google-colab fastdtw scipy
```

```
[ ] import cv2
    import numpy as np
    import mediapipe as mp
    import torch
    import torch.nn as nn
    from torch.utils.data import Dataset, DataLoader
    from scipy.signal import find_peaks
    from fastdtw import fastdtw
    from scipy.spatial.distance import cosine
    from dataclasses import dataclass
    from typing import List, Tuple, Optional, Dict
    from pathlib import Path
    import matplotlib.pyplot as plt
```

```
processor = DeadliftProcessor()
trainer = DeadliftFormTrainer(processor)
# Load the saved model
input_size = 24  # Number of landmarks * 3 (x,y,z) for 8 keypoints
trainer.model = DeadliftScorer(input_size).to(trainer.device)
trainer.model.load_state_dict(torch.load('best_model.pth'))
trainer.model.eval()  # Set to evaluation mode

# Now you can use the loaded model to make predictions
test_dir = "/content/drive/MyDrive/AI in Healthcare/Final Project/data/videos/test/test_02.mp4"
predictions = trainer.predict(test_dir)
print(f"Overall form score: {predictions['overall_score']:.3f}")

# Display visualization for each rep
for rep_idx, vis_frames in enumerate(predictions['rep_visualizations']):
    print(f"\nDisplaying Rep {rep_idx + 1}")
    print(f"Average Score: {np.mean(predictions['rep_scores'][rep_idx]):.3f}")

    # Show every 10th frame
    for i in range(0, len(vis_frames), 10):
        cv2_imshow(vis_frames[i])
        if cv2.waitKey(30) & 0xFF == ord('q'):
            break
```


```
[ ] from torch.utils.data import Dataset, DataLoader
    from scipy.signal import find_peaks
    from fastdtw import fastdtw
    from scipy.spatial.distance import cosine
    from dataclasses import dataclass
    from typing import List, Tuple, Optional, Dict
    from pathlib import Path
    import matplotlib.pyplot as plt
```

```
processor = DeadliftProcessor()
trainer = DeadliftFormTrainer(processor)
# Load the saved model
input_size = 24  # Number of landmarks * 3 (x,y,z) for 8 keypoints
trainer.model = DeadliftScorer(input_size).to(trainer.device)
trainer.model.load_state_dict(torch.load('best_model.pth'))
trainer.model.eval()  # Set to evaluation mode

# Now you can use the loaded model to make predictions
test_dir = "/content/drive/MyDrive/AI in Healthcare/Final Project/data/videos/test/test_02.mp4"
predictions = trainer.predict(test_dir)
print(f"Overall form score: {predictions['overall_score']:.3f}")

# Display visualization for each rep
for rep_idx, vis_frames in enumerate(predictions['rep_visualizations']):
    print(f"\nDisplaying Rep {rep_idx + 1}")
    print(f"Average Score: {np.mean(predictions['rep_scores'][rep_idx]):.3f}")

    # Show every 10th frame
    for i in range(0, len(vis_frames), 10):
        cv2_imshow(vis_frames[i])
        if cv2.waitKey(30) & 0xFF == ord('q'):
            break
```


```
[ ] print(f"Sequences : {predictions['rep_sequences']}")
    print(f"Scores : {predictions['rep_scores']}")
```

```
[ ] reference_dir = "/content/drive/MyDrive/AI in Healthcare/Final Project/data/videos/reference/deadlift_1.mp4"
    user_dir = "/content/drive/MyDrive/AI in Healthcare/Final Project/data/videos/user/deadlift_incorrect_01.mp4"

    # For single rep comparison
    results = processor.analyze_single_rep(reference_dir, user_dir)
    print(f"Overall similarity: {results['overall_similarity']:.3f}")
```

```
[ ] # Display visualization
    for frame in results['visualizations']:
        cv2_imshow(frame)
        if cv2.waitKey(30) & 0xFF == ord('q'):
            break
```

```
[ ] import pandas as pd
    import matplotlib.pyplot as plt

    # Load the CSV file
    file_path = 'epoch_data.csv'  # Replace with the correct path if needed
    df = pd.read_csv(file_path)

    # Plot Training Loss and Validation Loss
    plt.figure(figsize=(10, 6))
    plt.plot(df['Epoch'], df['Training Loss'], label='Training Loss', marker='o')
    plt.plot(df['Epoch'], df['Validation Loss'], label='Validation Loss', marker='s')
    plt.xlabel('Epoch')
    plt.ylabel('Loss')
    plt.title('Training and Validation Loss Over Epochs')
    plt.legend()
    plt.grid(True)
    plt.show()

    # Plot Learning Rate
    plt.figure(figsize=(10, 6))
    plt.plot(df['Epoch'], df['Learning Rate'], label='Learning Rate', marker='^', color='orange')
    plt.xlabel('Epoch')
    plt.ylabel('Learning Rate')
    plt.title('Learning Rate Over Epochs')
    plt.legend()
    plt.grid(True)
    plt.show()
```

THANK YOU