Angle Measurement for Running Exercise Analysis

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1. Abstract

This project addresses the challenge of analyzing joint angles during running exercises using data from the MR3 plantar pressure system and the Nexus motion capture system. By synchronizing data from these two sources, we can calculate and visualize knee, pelvis, hip, and ankle angles throughout a running cycle. The core of the project involves processing MR3 data to identify cycle start and end frames, then mapping corresponding angle data from Nexus files. A key challenge lies in handling the variable lengths of running cycles and inconsistent Nexus file segmentation. The developed methods allow for the calculation of average joint angles and their standard deviations throughout different phases of a running cycle.

2. Introduction

Analyzing running biomechanics is crucial for optimizing performance and preventing injuries. Joint angles, particularly at the knee, hip, ankle, and pelvis, are key indicators of running form and efficiency. This project aims to develop an automated pipeline for analyzing these angles using data collected from two different systems: the MR3 plantar pressure system and the Nexus motion capture system. The primary challenge is the need to synchronize these systems, deal with segmented Nexus data, and accommodate the variability in running cycle lengths. This project's output provides valuable insights into running mechanics that can be used by researchers, coaches, and athletes to improve training and performance.

3. Problem Statement

The goal is to record and analyze the following angles during running: Knee, Pelvis, Hip, and Ankle Angle. These angles must be represented as a function of time within a single running cycle. We use MR3 software to simulate and record plantar pressure data from a treadmill, allowing us to determine the start and end times of foot contact for each leg. Nexus software provides motion capture data with angle recordings synchronized to the MR3 system. However, Nexus output files are excessively large, requiring engineers to manually segment them before processing. Therefore, the problem focuses on automating the process of mapping the cycle start/end times from MR3 data to the segmented Nexus angle data to generate meaningful angle profiles for each running cycle.

4. **Input Description**

- **2.1 MR3 Output File:** Contains plantar pressure information for each frame, corresponding to the left and right legs. Crucially, it also contains the starting time (time when the file was cut) for each corresponding Nexus output file.

- **2.2 Nexus Output File:** Contains angle information recorded for each frame (consistent units with the MR3 output) along the X, Y, and Z axes in 3D space. These files are pre-segmented.

5. **Methodology**

5.1. **Cycle Identification**

The process begins by creating "Processed" files containing cycle information. We analyze the MR3 output file to identify the start and end frames for each running cycle. We also derive information about the stance phase percentage, initial phase percentage, mid-phase percentage, and terminal phase percentage for each cycle. The output of this step are Excel files named processed_left and processed_right.

5.2. **Data Synchronization**

The next step involves connecting the angle data from the Nexus files to the corresponding frames in the MR3 data.

- **Function: connect_angle_to_frame:**

  - Reads MR3 and Nexus files.

  - Converts timestamps to datetime format.

  - Calculates the time difference between the start times of the two files. This allows aligning Nexus data to the correct MR3 timeline. The starting time of Nexus is considered time start of MR3 + time difference.

  - Extracts relevant angle data from Nexus files. This involves skipping rows until reaching the 'Model Outputs' key within the Nexus file's dictionary structure.

- **Function: read_csv_with_skiprows:**

  - Determines the correct number of rows to skip in the Nexus file based on its filename (whether it contains numbers or not). This addresses the inconsistent index of the "Model Outputs" key in Nexus files.

- **Function: get_index_of_column:**
    - Dynamically identifies the correct column index for the desired angle based on whether the column name contains "side + angle_name". This ensures that the correct angle data is extracted, regardless of column order in different Nexus files.
- The function extracts the angle data with the length of Nexus file, then merging angle and time data.

5.3.   Data Aggregation and Cycle Extraction

- **Dataframe concatenation**
    - **Function: create_combined_dataframe:** All Dataframes, corresponding to Nexus output file, are merged vertically.
- **Cycle-Based Dataframe Creation:** A Dataframe is generated to represent angle data for each cycle. The algorithm iterates through the start and end frames identified in the processed files and extracts corresponding angle data from combined dataframes.
    - **Addressing Cycle Anomalies:** Due to irregularities in foot contact, some cycles may be misidentified with excessively long durations. Engineers review the processed files and manually remove such cycles.
    - **Angle Extraction:** The function iterates through the start and end frames of each cycle.
    - The functions will retrieve all angle value from Nexus files, and extract data between those start, end frames, and append those angle values to a list.
    - Dataframe is created to represent cycle.

5.4.   Normalization and Averaging

- **Angle Averaging with Cycle Normalization:** Due to the variability in running speed, each cycle has a different number of frames. To facilitate comparisons, each cycle is normalized to a fixed number of data points by scaling the angle data.
- **Function: calculate_mean_and_std_angles:** Averages angle values across multiple cycles at each normalized point (representing a percentage of the cycle). This enables plotting of average angle profiles with standard deviation bands.

5.5.   Visualization

- **Plotting:**
  - Plots the average angle trajectories and standard deviation bands for each joint (knee, hip, ankle, pelvis) during the running cycle.
  - Shows the average time of phase base on processed file information, and standard deviation on the line.

6. Discussion

The results demonstrate the effectiveness of the developed pipeline for analyzing joint angles during running. The synchronization of data from MR3 and Nexus systems allows for a comprehensive assessment of running biomechanics. However, the manual segmentation of Nexus files and the need for manual cycle filtering present limitations.

7. Conclusion

This project successfully developed a pipeline for measuring and analyzing joint angles during running by integrating data from MR3 and Nexus systems. The pipeline addresses challenges related to data synchronization, cycle identification, and variable cycle lengths.

Code from the project is being used by engineers at Motion Lab Analysis - Vinmec