**Project Overview**

* **Title:** ROLE OF FORELIMB MORPHOLOGY IN MUSCLE SENSORIMOTOR FUNCTIONS DURING LOCOMOTION IN THE CAT
* **Components:** 13 parts providing a comprehensive model of the cat's forelimb neuromechanics.

**General Notes**

* Main scripts begin with 'A\_', 'B\_', etc., and must be run in sequence.
* Abbreviations:
  + "OW" and "OV" (same): Muscle Origin to Muscle Via-point
  + "WI" and "VI" (same): Muscle Via-point to Muscle Insertion

**Description of Each Part**

**A) Muscle Length and Moment Arm**

* **A1 - Musculoskeletal data**
  + Scripts:
    - [A\_MusculoskeletalSystem\_SagittalPlane](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/A%29%20Muscle%20length%20and%20moment%20arm/A1%20-%20Musculoskeletal%20data): Loads data from Excel sheets containing your experimental data (musculoskeletal information). It performs the following:
      * Extracts muscle origin and insertion points, joint centers, and other relevant anatomical data.
      * Fits a plane to the attachment points using Principal Component Analysis (PCA) and projects anatomical landmarks for accurate spatial representation.
      * Plots the muscles and segments in a 3D figure, visualizing the fitted plane, annotating muscles and attachment points, and highlighting key anatomical features.
    - [B\_Musculoskeletal\_Visualization\_2D\_3D](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/A%29%20Muscle%20length%20and%20moment%20arm/A1%20-%20Musculoskeletal%20data): Performs 2D and 3D visualization of selected muscles. Computes rotations to align anatomical points on the computed sagittal plane with the XY plane. It also:
      * Computes muscle lengths and geometrical parameters.
      * Estimates segment lengths and angles.
      * Creates a structure named 'MusculoskeletalData' for further analysis.
* **A2 - Computation of muscle length and moment arm**
  + Script: [A\_RunAll](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/A%29%20Muscle%20length%20and%20moment%20arm/A2%20-%20Computation%20of%20muscle%20length%20and%20moment%20arm) processes all sub-scripts related to individual muscles. It performs the following:
    - Scales musculotendon attachment points.
    - Computes musculotendon length, velocity, and moment arm during locomotion for each muscle.
    - Generates two structures: 'MuscleLengthVelocityMomentArm' and 'ScaledMuscleMorphologicalParameters' for further analysis.

**B) Muscle mechanical properties**

* Script: [A\_Muscle\_Mechanical\_Properties](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/B%29%20Muscle%20mechanical%20properties) creates a table named 'MuscleMP' containing muscle mechanical properties derived from our experimental data in the Excel sheet titled 'ForelimbArchitecture'. This table will be used for further analysis.

**C) Muscle dynamics based on fixed tendon length computed at maximum musculotendon length (MTL)**

* Script: [A\_Maximum\_Muscle\_Force\_Moment\_Computation](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/C%29%20Muscle%20dynamics%20based%20on%20fixed%20tendon%20length%20computed%20at%20maximum%20MTL) computes the maximum musculotendon forces and moments resulting from maximum activation during locomotion. The results are saved in a structure array 'MaxMuscleForceMoment'. It uses input data including:
  + Cycle time from 'MotionData'
  + MT length, velocity, and moment arm data from 'MuscleLengthVelocityMomentArm'
  + Muscle mechanical parameters from 'MuscleMP'
* Script: [B\_Plot\_3in3\_figs](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/C%29%20Muscle%20dynamics%20based%20on%20fixed%20tendon%20length%20computed%20at%20maximum%20MTL) calculates the biomechanical variables of a selected MT unit during locomotion based on input data including:
  + Cycle time from 'MotionData'
  + MT length, velocity, moment arms from 'MuscleLengthVelocityMomentArm'
  + Muscle mechanical parameters from 'MuscleMP'
* Generates plots to visualize these variables over a locomotion cycle.

**D) Muscle clustering based on constant tendon length computed at maximum MTL**

* Script: [A\_Muscle\_Clustering](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/D%29%20Muscle%20clustering%20based%20on%20constant%20tendon%20length%20computed%20at%20maximum%20MTL) performs k-means clustering on maximum muscle moments and compares it with function-based grouping. It generates the 'MuscleCluster' cell array, which shows the cluster of muscles in each cell.

**E) Mechanical properties of 9 muscle groups**

* Script: [A\_Muscle\_Mechanical\_Properties\_9\_Groups](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/E%29%20Mechanical%20properties%20of%209%20muscle%20groups) calculates and summarizes the mechanical properties of 9 muscle groups based on the clustering results and mechanical properties of 40 muscles. It computes:
  + Mean for each equivalent muscle related to each group (except mass and PCSA parameters, which are summed).

**F) Muscle Morphology Optimization (9 Muscle Groups)**

* **F1) Initial Morphologic Parameters of 9 Muscle Groups**
  + Script: [A\_InitialMusculoskeletalData\_9\_Groups](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/F1%29%20Initial%20Morphologic%20parameters%20of%209%20muscle%20groups)
    - Generates initial morphological parameters ('a' and 'phi') for 9 muscle groups.
    - Includes joint radius ranges based on individual muscles in each group.
    - Computes ranges for other morphological parameters (including 'a' and 'phi') from SolidWorks drawings.
    - Saves generated data in 'NineMuscleMorphParaInitial' for further analysis.
* **F2) Optimization to Tune 9 Muscle Groups Morphological Parameters**
  + This folder tunes the geometric parameters to match the maximum moment of the original muscle groups.
  + It uses an interior point optimization algorithm and includes 10 subfolders:
    - Folders 1-9: Each optimizes a specific muscle group.
    - Consolidated folder: Combines the results of all groups.
  + Script: [A\_RunAll](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/F2%29%20Optimization%20to%20tune%209%20muscle%20groups%20morphological%20parameters/Creating%20MT\_LVMA\_9Groups%2C%20MaxMTFM\_9Groups%20%26%20MTData\_9Groups) (within the consolidated folder)
    - Creates:
      * MuscleLengthVelocityMomentArm\_9Groups: Musculotendon length, velocity, and moment arm during locomotion (for 9 groups).
      * MusculoskeletalData\_9Groups: Joint centers, muscle origins/insertions, and geometric parameters during locomotion (for 9 groups).
      * MaxMuscleForceMoment\_9Groups: Musculotendon force, moment, fascicle length, tendon length, etc. during locomotion with maximum activation (for 9 groups).

**G) Musculoskeletal System Animation**

* This folder contains two subfolders for animating the cat's forelimb during locomotion:
  + **Subfolder 1:** Animation with joint angular velocities and moments displayed as circular arrows.
  + **Subfolder 2:** Animation of the musculoskeletal system without additional details.

**H) Muscle Activation Computation**

* **H1) Computation of Muscle Activations for 40 Muscles**
  + Script: [A\_Optimization](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/H1%29%20Computation%20of%20muscle%20activations%20for%2040%20muscles)
    - Minimizes muscle fatigue for 40 muscles using a cost function.
    - Optimization parameters are muscle activations.
    - Employs static optimization with random initial conditions for stable convergence.
    - Constrained by Constraint\_Function to ensure joint moments equal the sum of corresponding muscle moments.
  + Script: [B\_Results](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/H1%29%20Computation%20of%20muscle%20activations%20for%2040%20muscles)
    - Loads optimal muscle activations from 'Activations.mat' (created by A\_Optimization).
    - Computes muscle forces and moments, calculates the sum of muscle moments at each joint using Results\_Function.
    - Compares joint moments with the sum of corresponding muscle moments for equality.
    - Generates plots for user-selected muscle activation.
* **H2) Computation of Muscle Activations for 9 Muscles** (Similar process to H1)
  + Script: [A\_Optimization](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/H2%29%20Computation%20of%20muscle%20activations%20for%209%20muscles) (for 9 equivalent muscles)
  + Script: [B\_Results](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/H2%29%20Computation%20of%20muscle%20activations%20for%209%20muscles) (for 9 equivalent muscles)

**I) Comparison of EMG Data and Computed Activations**

* Script: [A\_EMGs\_Individual\_Combined\_Muscles\_WithSecondAxis](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/I%29%20EMGs%20vs%20computed%20activations)
  + Processes and compares muscle activations from individual muscles and their equivalent muscles with EMG data.

**J) Sensory Feedback Computation**

* Script: [A\_Sensory\_Feedbacks](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/J%29%20Computation%20of%20sensory%20feedback)
  + Processes and analyzes sensory feedback in cat locomotion (Ia, II, and Ib afferent activities).
  + Uses muscle activations, muscle-tendon lengths/velocities/forces (for individual muscles and equivalent groups).
  + Saves normalized results for further analysis.
* Script: [B\_Spinal\_Map\_Sensory\_Feedbacks](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/J%29%20Computation%20of%20sensory%20feedback)
  + Computes a spinal map of motor and sensory neuron activities during the walking cycle.
  + Uses proportional motor pool distribution from literature.

**K) Sensitivity Analysis**

* Performed in 9 separate subfolders (Sensitivity Analysis Group 1 to 9).
* Analyzes how changes in major physiological/mechanical and geometrical parameters affect maximum moment of equivalent muscle.
* Each subfolder includes a script: [A\_MT\_Sobol\_Sensitivity\_Analysis](https://github.com/smarahmati/CatForelimbNeuromechanics/tree/master/Codes/K%29%20Sensitivity%20analysis/Sensitivity%20Analysis%20Group%201)
  + Computes sensitivity of mean maximum MT moment to muscle parameter changes.
  + Uses Sobol method implemented in SobolGSA software (Kucherenko & Zaccheus, 2016).
  + Requires downloading and installing the Global Sensitivity Analysis Toolbox (<https://www.mathworks.com/matlabcentral/fileexchange/40759-global-sensitivity-analysis-toolbox>).
* Sensitivity analysis results can be plotted in the corresponding 'GraphSensitivity' subfolder.