Innervation model for the study of the recruitment patterns in intramuscular electrical stimulation

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Description: This model creates an artificial intramuscular nerve distribution. A pool of motor units (motor neuron + muscle fibers) is generated and the axons geometries are defined by the intramuscular innervations. Once the model is built it allows placing point source electrodes at any location within the muscle to simulate the muscle response to a single electric pulse delivered by the electrodes. The model simulates the axons responses to the electric pulse and calculates the number of muscle fibers that twitch based on the axons in which an action potential is initiated. The muscle model is intended to represent a spindle shaped unipennate muscle with a single nerve entering the muscle in one of the extremes. Muscle fibers are innervated by a single motor end-plate region which is located at approximately the muscle center.

Model structure:

The steps to generate the model are:

- Creation of an intramuscular nerve tree: The first step in the generation of the model consists in the creation of the intramuscular nerve distribution. At this step the intramuscular nerve spatial distribution is generated through a series of branching levels. The nervous geometry joins each neuromuscular junction with the nerve trunk.

- Creation of a motor unit pool: This step creates a motor unit population with different twitch forces.

- Integration of the motor unit pool into the intramuscular nerve distribution: Based on the twitch force of each motor unit, a number of muscle fibers are randomly assigned to them. Each muscle fiber has a path associated to it in the intramuscular nerve distribution. Therefore, the muscle fibers associated to each motor unit define the geometry of its axon.

- Generate the motor neuron axons: The previous step defined the paths and the branching patterns of each axon. The last step in the model generation is the calculation of the exact locations of the nodes of Ranvier of each of these axons.

Muscle response:

Once the model has been built, it is possible to calculate the muscle response to an electric stimulus delivered by a monopolar electrode located anywhere within the muscle. By defining the electrode location, the stimulus current and the pulse length the model can simulate the response of each axon to the stimulus. The outputs are the motor unit activity (either an action potential has been initiated in the axon or not) and the muscle twitch force (based on the number of muscle fibers innervated by the axons that have been activated).

Main routines:

- *model_data_tree.m*
  - o Description: Parameters that define the model (nerve arborization patterns, MU pool properties, muscle dimensions…).
- *Generate_nerve_tree.m*
  - o Description: This routine creates the intramuscular nerve distribution. The output consists in an array of points that defines the paths taken by the nerve branches.
  - o Inputs: Parameters defined in the script *model_data_tree.m*
  - o Output: *nervetree.mat*
- *create_motor_units.m*
  - o **Description:** This routine creates a motor unit pool and assigns the neuromuscular junctions from the intramuscular nerve distribution created by the previous routine to these motor units. Once the neuromuscular junctions are associated to motor units, this information is used to trace the entire paths described by each motor unit axon from the nerve trunk to the neuromuscular junctions. For each motor unit, a list of points from the intramuscular nerve distribution (*nervetree.mat*) is extracted. This information will be used later to define the geometry of the axons.
  - o **Inputs:** Parameters defined in the script *model_data_tree.m* and intramuscular nerve distribution created in the previous step (*nervetree.mat*).
  - o **Output:** *mu_tree.mat*
- *create_axons.m*
  - o **Description:** This routine calculates the locations of the Nodes of Ranvier for each motor unit axon. This is done based on the axon paths and its diameter.
  - o **Inputs:** Parameters defined in the script *model_data_tree.m,* intramuscular nerve distribution (*nervetree.mat*) and motor unit paths (*mu_tree.mat*)
  - o **Output:** *Ranvier.mat*
- *Contraction_force.m*
  - o **Description:** Once the model is built, this routine calculates the response of the muscle to an electrical pulse delivered by a point electrode.
  - o **Inputs:** Parameters defined in the script *model_data_tree.m* and positions of the nodes of Ranvier (Ranvier.mat). Other parameters that are defined within the script: muscle resistivity, electrode position, pulse length, electrode current.
  - o **Output:** *activity* (motor unit response: 1 if an action potential has been initiated 0 if no action potential is initiated) and *twitch* (relative force in response to the stimulus)

Plot routines:

- *plot_tree.m:* This script plots the intramuscular nerve distribution. Every major branch and its daughter branches are plotted with a different color.
- *plot_MU_pool.m:* This script plots the motor unit pool properties after the motor unit pool integration into the muscle nerve distribution.
- *Plot_axon.m:* This script plots the nodes of Ranvier of an axon.