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Topic 1: Biomechanics in MuJoCo: Tissue Modelling and FEA (3-4 students)

Background: MuJoCo is a widely used open-source tool in robotics and machine learning. It is capable of dynamics and physics simulations, making it an invaluable instrument for robotics, biomechanics, and animation.
Despite the capability of MuJoCo in rigid and simple soft body simulations, there are limitations in simulating contact and collision. Integrating finite element analysis (FEA) in carefully selected moments of the simulation could improve their accuracy by allowing for more detailed and realistic modeling of the motion and dynamics.
Furthermore, in biomechanical analysis, FEA could provide an accurate analysis of loads and stresses on bones, joints, muscles, and ligaments. This would greatly benefit the medical analysis of movement patterns and injuries, as well as the development of prostheses and exoskeletons, providing valuable insight into designing devices for supporting and enhancing human movement.

Tasks:

- Research into FEA options to be used in MuJoCo, including contact considerations
- (Automated?) Tessellation and other preliminary steps of FEA
- Selection of critical moments and areas of simulation for FEA
- Consolidation of control forces and multiple materials with the FEA

Prerequisites:

- Finite element analysis (preferred)
- Programming in C++ or Python (mandatory)
- Understanding of kinematic chains from robotics, biomechanics or animation (preferred)

References:

- MuJoCo: https://mujoco.org/ https://github.com/deepmind/mujoco
- OpenSim: https://simtk.org/projects/opensim
- FEBio: https://febio.org/ https://github.com/febiosoftware/FEBio

Topic 2: Biomechanics in MuJoCo: Model Selection and Comparison (1 student)

Background: MuJoCo is a widely used open-source tool in robotics and machine learning. It is capable of dynamics and physics simulations, making it an invaluable instrument for robotics, biomechanics, and animation.
In medical analysis, as well as the development of prostheses, having the correct biomechanical model is critical. While MuJoCo as a platform provides a powerful simulation engine, it relies on external libraries for extensive visualizations and comparisons of models. Additionally, the integrated visualizations on the platform are limited. Developing integrated visualizations and automatic tools for model selection for musculoskeletal models would help in comparing different models and designs.
These visualizations about the musculoskeletal models would enable users to easily analyze the behavior of joints, muscles, and ligaments, as well as the forces and stresses

acting on them. Automatic comparison of the simulated data would aid in the design of the model and prostheses.

Tasks:

- Research and implementation of different visualization techniques specifically for musculoskeletal models. MuJoCo does contain basic bone visualizations, but not graphs, figures, or biomechanics-specialized visualizations.
- Research and implementation of automated comparison for different joints, muscles, forces, and stresses between multiple models. This should be generic enough to handle e.g. the same system with different muscle configurations, or the same situation with a different number of joints.
- Testing the above with a number of biomechanical models.

Prerequisites:

- Programming in C++ or Python (mandatory)
- Understanding of kinematic chains from robotics, biomechanics or animation (preferred)

References:

- MuJoCo: https://mujoco.org/ https://github.com/deepmind/mujoco
- OpenSim: https://simtk.org/projects/opensim

Topic 3: Biomechanics in MuJoCo: Real-Life Data (1-2 students)

Background: MuJoCo is a widely used open-source tool in robotics and machine learning. It is capable of dynamics and physics simulations, making it an invaluable instrument for robotics, biomechanics, and animation.

While MuJoCo handles kinematic and dynamic simulations, it does not integrate any capabilities of inverse kinematics. This limits the validation of models and animation of data, especially in the domain of biomechanics where model comparisons with real-world data are critical.

There are several approaches that could be taken to address this limitation. One option would be to use skeletal motion data or motion capture sets to find the valid motion and then adjust it based on the dynamics of the model. Another approach would be to use pose detection algorithms from video data, which could then be translated into MuJoCo to generate more accurate simulations.

Tasks:

- Aggregation of video and motion capture datasets about movement
- Research and application of pose detection algorithms
- Implementation of inverse kinematics and dynamics in MuJoCo

Prerequisites:

- Programming in C++ or Python (mandatory)
- Understanding of kinematic chains from robotics, biomechanics or animation (preferred)
- Understanding of deep learning (preferred)

References:

- MuJoCo: https://mujoco.org/ https://github.com/deepmind/mujoco
- OpenSim: https://simtk.org/projects/opensim
- O2MConverter: https://github.com/aikkala/O2MConverter
- YOLO v7 (pose detection): https://github.com/WongKinYiu/yolov7
- SimPoE: https://ye-yuan.com/simpoe/