PhD Thesis Proposal Form
China Scholarship Council (CSC)/ENS Rennes
Call for projects 2018

FIELD open

Thesis subject title: Constrained dynamics for musculoskeletal analysis in real time: toward alternative muscle forces estimation methods

- Laboratory name: IRISA UMR 6074
- PhD supervisor (contact person):

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- Thesis proposal (max 1500 words):

Musculoskeletal simulation is a domain in constant progress. Its goal is to provide to experts biomechanical quantities that are not directly measurable on a subject: joint reaction forces, joint torques or forces generated by muscles for example. Classically, motion is captured using an optoelectronic system and external forces are measured using force sensors (force platforms…). Some of the muscle activities can be measured with electromyography electrodes. These measurements are used as an input of a MSM dynamics simulation used to predict the biomechanical quantities characterizing the studied motion. Musculoskeletal simulation can have a real impact on the society, with multiple applications, e.g. sports sciences, ergonomics, clinics…

The reliability of such simulations (i.e. the capacity to predict quantities close to the ground truth) is mostly based on the realism of the model, the accuracy of the measures and the capacity of the methods to properly mimic the Central Nervous System (CNS) behavior.
To address this last issue, numerous software propose musculoskeletal simulations based on inverse dynamics methods, even in real time. In such software using inverse dynamics based methods, the force sharing problem is solved thanks to optimization methods. The force sharing problem is assumed to be an optimization problem, consisting in minimizing a criterion representing a central nervous system (CNS) strategy. The criterion represents a cost, e.g. metabolic energy, muscle fatigue

or joint reaction force. However, optimization remains costly in terms of computation time, despite of several implementations and improvements in the last years. Mostly, the use of Sequential Quadratic Programming Methods (SQP) have deeply improved the computation times since the muscle forces estimation problem is well shaped for such an algorithm.
However, in real-time simulations including muscle forces estimation, the result remains sub-optimal. Muscle can be gathered by functional groups to reduce the problem complexity, but that lead to strong bias in the estimated forces. In other works, the use of a neural network dedicated to quadratic optimization led to a real-time but sub-optimal result, since computation time was limited to ensure real-time computation.
To circumvent this issue, we proposed a fast and quasi-optimal method of muscle forces estimation, the MusIC method (Muscle forces Interpolation and Correction) based on interpolation.

The MusIC method is based on two main hypotheses:

- the muscle forces problem can be first solved joint per joint and the inter-joint muscular coupling (multi-articular muscles) can be taken into account a posteriori;
- the muscle forces can be corrected to respect the dynamic equilibrium.

The method has been proved to be at least ten times faster at runtime than classical optimization for similar results in terms of optimality. This rapidity is of first importance because it allows the user (subject) to analyze her/his motion or gesture while performing it and so allows to learn how to improve this motion or gesture.

However, limitations remained:

- First, the method only applies to open-loop models, meaning that no complex architecture including kinematical loop can be used with the method;
- Second, the method asks for a database generation that can be time consuming. There is a need of simplification of the database;
- Third, the method is unable to take into account muscle activation dynamics;
- Last, the database gives results based on the joint configuration only, whereas angular velocities have to be taken into account since muscles are visco-elastic actuators.

Therefore, the aim of the current PhD thesis subject is the extension of this muscle forces interpolation method to constrained dynamics and its enhancement in terms of computation time, activation dynamics and actuation models.

To achieve this goal, a methodology in three steps will be developed:

- First, after a meticulous review of the current methods available to achieve inverse dynamics in real-time, the candidate will have to develop a whole body inverse dynamics algorithm able to express actuation forces thanks to acceleration, speed and position quantities under kinematical constraints. This formulation will be used as an input of an optimization method to achieve a classical muscle forces estimation based on the minimization of a cost function under physiological and dynamical constraints. This algorithm will be validated thanks to an experimentation based on motion capture data and EMG measurements. This development will be made on the basis of the current musculoskeletal library developed and maintained by the team.

- Second, on the basis of the previous work, a new database of forces will be generated. A particular attention will have to be made about the database inputs to achieve. Model reduction will be used to diminish the number of parameters to be known to characterize the current force configuration of a given model.
- Last, an extension of the MusIC method, using this new database, will be proposed. It will consist in the interpolation and correction of muscle forces based on constrained dynamics. The key point will be to maintain a trade-off between precision of results and computation time allowing an analysis at runtime.
- In order to validate the proposed method, experiments involving people will be proposed. These experiments will be performed in the Immerstar platform, operated by the research team in which the thesis will take place, that consists in a platform, Immersia, dedicated to research in virtual reality (http://www.irisa.fr/immersia/) and a platform, Immermove, that is an immersive room associated to a sport stadium dedicated to motion studies both in real and virtual environments (http://m2slab.com/index.php/facilities-4/).

- Publications of the laboratory in the field (max 5):

- Pierre Plantard, Antoine Muller, Charles Pontonnier, Georges Dumont, Hubert Shum, Franck Multon, *Inverse dynamics based on occlusion-resistant Kinect data: Is it usable for ergonomics?*, International Journal of Industrial Ergonomics, Elsevier, 2017. (10.1016/j.ergon.2017.05.010).

- Antoine Muller, Charles Pontonnier, Georges Dumont, *Uncertainty propagation in multibody human model dynamics*, Multibody System Dynamics, Springer Verlag, 2017. (10.1007/s11044-017-9566-7).

- Antoine Muller, Charles Pontonnier, Georges Dumont, *The MusIC method: a fast and quasi-optimal solution to the muscle forces estimation problem*, Computer Methods in Biomechanics and Biomedical Engineering, 2018, to appear

- Charles Pontonnier, Mark De Zee, Afshin Samani, Georges Dumont, Pascal Madeleine, *Strengths and limitations of a musculoskeletal model for an analysis of simulated meat cutting tasks*, Applied Ergonomics, Elsevier, 2014. (10.1016/j.apergo.2013.08.003).

- Charles Pontonnier, Georges Dumont, Inverse dynamics method using optimization techniques for the estimation of muscles forces involved in the elbow motion, International Journal on Interactive Design and Manufacturing, Springer Verlag, 2009. (10.1007/s12008-009-0078-4).

▪ Joint Phd (cotutelle) :	NO	YES or NO
▪ Co-directed PhD :	YES	YES or NO

In case of a co-directed or a joint PhD, please detail: The thesis will be co-supervised by Charles Pontonnier, associate professor at ENS Rennes and expert in musculoskeletal analysis.

- Partner university name: ENS Rennes
- Laboratory name and web site: IRISA UMR 6074 (www.irisa.fr)
- PhD co-director (contact person):
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- Provisional duration and timetable of the PhD student's stay at ENS Rennes:

  3 years

- If previous collaborations with the Chinese co-director/university, please detail:

  NA

- Interest of the Joint PhD for the French co-director, for his/her laboratory, for ENS Rennes:

NA

Date:

Signature of the PhD director | Name and signature of the Laboratory director