PhD proposal

Musculoskeletal simulation and Elastic Structure for Sports

(MUSES)

Project summary

Elasticity plays a major role in performance in many sports activities involving contact between the athlete and his environment. This sport-material interaction describes two systems, usually considered in isolation, as a coupled approach to study the deformations and vibrations induced by the athlete as well as the human biomechanical responses to these deformations or vibrations. The athlete must adapt his technique using the maximum elastic properties of his equipment. This involves adapting the athlete's biomechanics to the characteristics (length, stiffness, etc.) of his equipment. The athlete's strategy therefore consists not only of transforming the kinetic energy acquired during the movement into potential energy for the structure, but also of judiciously creating efforts on the material to achieve optimal movement using the deformation energy.

This project aims to develop a model of physical sports interaction that links human biomechanics and dynamics of structures. This new approach will consist of applying human biomechanical knowledge to the field of dynamics of deformable structures used in certain sports specialties and identifying dynamic characteristics of the interaction to achieve optimal movement.

Thesis topic

Positioning

In the context of musculoskeletal simulation, there has been little work on energy transfers. The most significant work concerns the simulation of walking and running (Rajagopal et al., 2016, Sasaki and Neptune, 2006).

From a structural dynamics point of view, most of the work on human-material interaction has focused on human actions on structures through static (e.g. standing, seated), motion coupled according to a temporal approach (e.g. localized and standardized jump) or according to an analysis of the displacement in space and time (e.g. race, jump with momentum).

Thus, human biomechanical models in dynamics of structures and vibrations have been represented through the following approaches:

- modeling by a mobile loading when the athlete moves
- modeling in the form of a mass-spring-damper system (mainly during localized movements, e.g. 1D in vertical displacement).

Since few studies model the athlete in interaction as a complete biomechanical model (musculoskeletal), the question of energy transfer levels and optimal timing synchronizations remains open.

The search for improved performance through innovative scientific solutions to study the coupling between the athlete and his equipment is timely in view of the deadline of the Olympics in France. The generic character of the model will enrich the knowledge of coaches and athletes and, in the long term, we believe that the results obtained will allow a better knowledge and a better conception of the technical materials intended for the sports.

Assumptions and key scientific points

To date, regardless of the interaction with the material, the biomechanical literature has addressed the energy assessments during the movement mainly through the notion of mechanical work. This work was quantified using different methods to identify contributions in terms of external work, internal work and joint work. External mechanical work is the mechanical work produced by an external load -e.g. in pedaling (van Ingen Schenau et al., 1990) - and by the movement of the center of mass -e.g. in running (Cavagna et al., 1963-). Internal work is usually defined as the work required to move body segments relative to the center of mass. The latter can be calculated through variations in kinetic energy and potential energy during movement (Cavagna and Kaneko, 1977, Winter, 1979). However, internal and external work has several limitations for the quantification of energy transfers during human movement. Thus, there is some ambiguity regarding the transfer of energy between body segments (Willems et al., 1995) and a lack of independence between internal and external work that does not allow to calculate the mechanical work as a simple sum of two measures (Aleshinsky, 1986a, Kautz and Neptune, 2002). Moreover, these estimates provide only a fragmentary view of the mechanical work produced by muscles taken individually during motor tasks (Aleshinsky, 1986b, Kautz and Neptune, 2002). Joint work, calculated as the temporal integral of articular net powers by a standard inverse dynamic approach, is supposed to represent musculotendinous work more accurately than by internal and external work. The benefits of joint work on the internal / external work approach has been demonstrated in previous studies of pedaling, walking and running tasks (Alexander 1992). The approach by the estimation of the articular works admits a certain number of limitations. One of the main limitations is the inability of most of the models used to account for the individual contributions of muscles to external mechanical work, mainly because of co-contraction inducing a net moment lower than the sum of bending moments and extension for the individual muscles. In addition, the elastic energy stored and released by the tendons can induce negative work that can be transformed into positive work in another phase of the movement. To overcome these limitations, musculoskeletal modeling is an appealing solution to estimate the energy contributions of each muscle head during the movement (Pouliquen2018, Muller2018, Muller2018, Muller2019). Until now, this type of model has focused on the biomechanics of the musculoskeletal system in relation to external forces that do not emanate from deformable structures.

Methodology

Starting from the construction of a generic model of interaction between an athlete and a slender deformable structure, two main applications are envisaged:

- Pole vault
- Olympic diving

Indeed, in each case the material used provides an effective means of converting the kinetic energy of the athlete into potential energy, by the ability of structures to flex and store elastic energy that could be restituted. Thus, a beam model seems particularly suited to represent the dynamic and energetic response of the sports equipment used while a musculoskeletal modeling approach will make it possible to evaluate the work and associated muscular efforts necessary to produce an optimal performance.

The realization of this project can be divived into the following steps:

- The application of biomechanical concepts to the analysis of the athlete in interaction with a deformable material during the realization of a movement:
    - Motion analysis on a whole body model,
    - Joint coordination and muscle,
    - Evaluation of internal and external efforts.

The establishment of a coupling model between a rigid multi-body system (human system) and a slender deformable structure (sports equipment), for example in the form of a 3D beam with a non-linear response. Special attention will be paid to the coupling resolution to integrate solution of the deformable system within the motion analysis solver. As a first step, a hybrid digital analytical approach will be considered.

- The identification of the global responses of the coupled system:
    - Evaluation of the energies involved and associated dissipations as well as the temporality of these energy transfers.
    - Intra-system and inter-system evaluations.

- The definition of optimality criteria for the interaction:
    - Optimization of material characteristics
    - Optimization of human movements (motor coordination, energy transfer between body segments, etc.)
    - Optimization and loadings (direction and intensity of effort) applied by the athlete.

The developments will be integrated in the OpenSource Platform CusToM.

Candidate profile

We are looking for a candidate to prepare a doctoral thesis in the fall of 2019. The candidate must have a master's degree in biomechanics or mechanics and, if possible, to demonstrate skills in computer development and in numerical methods. Experience using experimental tools (motion capture, electromyography, force platforms) will a real plus. A good level in international English will also be needed. A scientific curiosity and a taste for multidisciplinary work will also be appreciated.

Supervision

This project is carried out in a context of multidisciplinary research by:
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This PhD thesis will be held at the École Normale Supérieure in Rennes (ENS Rennes) within the MimeTic project team (https://team.inria.fr/mimetic/) at IRISA (UMR 6074), Inria Brittany research centre and M2S (EA 7470).

Granting and salary

The thesis is granted by the Region Bretagne and Ecole Normale Supérieure de Rennes. The grant is of ~1350€ per month. The candidate will complete its salary with courses at ENS Rennes (64h per year), allowing an additional salary of ~300€ per month.

Link :

- http://www.enseignementsup-recherche.gouv.fr/cid76053/le-financement-doctoral.html.

Experimental platform & facilities

The IMMERMOVE Immersive Room will be the main experimental platform used in this project, and has been partially funded under the latest Brittany State Plan Contract. It is carried in the framework of the Immerstar project by ENS Rennes, the University of Rennes 2, the University of Rennes, the INSA of Rennes and the INRIA Bretagne / Atlantique research center, all also associated with the IRISA UMR laboratory. 6074 whose team MimeTIC is one of the teams and also carried by the M2S (EA7470).

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