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Evaluation of the PhD Thesis of Mr. Maximilien Naveau

To whom it may concern,

I am writing this letter to evaluate the PhD thesis of Mr. Maximilen Gabriel Naveau. Before evaluating his thesis I did not have any direct collaboration or publications together with Mr. Naveau.
The thesis of Mr. Naveau presents solutions for locomotion control problems of humanoid robots. The thesis is interlinked with the research performed in the scope of the European project Koroibot from which also some key performance indices are derived and used in the performance evaluation of the different algorithms presented in the thesis. The thesis contains both new theory and an application of the theoretic results in a series of applications performed by means of real experiments on a full-scale humanoid robot HRP-2. The mathematical theories and algorithms applied by Mr. Naveau are in line with the considered control problems.
The thesis is organized in a well structured way, building up on existing results from the literature on humanoid walking control and extending these concepts to develop new ideas. The background on locomotion control is separated into an appendix or cited in the literature review. The first two chapters present the theoretical foundations of the thesis. Chapter one proposed an extension of a walking control approach based on model predictive control. While previous works have simplified the walking control problem by separating the foot step placement and the foot step orientations, Mr. Naveau treated these issues in a unified formulation, requiring to solve a nonlinear, and thus considerably more complex, optimization problem. Mr Naveau showed that despite the increased computational complexity this optimization can still be performed in real-time as certified by successful experiments on HRP-2. The second chapter treats multi-contact locomotion. This problem currently is a subject of very active research in the robotics community, and the contributions of Mr. Naveau add important aspects to the current knowledge base in the community. The multi-contact planning problem as formulated by Mr. Naveau is based on the centroidal dynamics which is considered together with the full rigid body dynamics of the robot. The resulting nonlinear model predictive control problem is solved by two separate algorithms, one of which comes close to real-time. While this algorithm can now be considered as a planning algorithm, future increase of the computational power of humanoid robots might allow to apply this algorithm in a feedback loop. In this context the experimental results of Mr. Naveau have shown that the overall energy consumption of the locomotion task can be reduced by use of additional contact points.
The following chapters in the thesis present some more complex tasks in which the proposed algorithms have been applied as basic building blocks together with some higher level algorithms required so solve the given tasks. The first considered task was the pulling of a stiff fire hose which presents a considerably disturbance to the locomotion control. The second task was the

realization of more human-like motions by transferring the ideas of the two third power law to the motion generation of humanoid robots. Collaboration with humans have been considered in the task presented in Chapter 5, in which human motion primitives are used for the upper body motion. In this case the change of the angular momentum due to the upper body motion can become larger such that the effects of the dynamics filter in the locomotion controller play a stronger role. The last chapter presented an industrial collaboration with the company Airbus, in which the performance of humanoid robots are evaluated in the context of Aircraft manufacturing tasks.

It should be emphasised that in the field of humanoid locomotion control Mr. Naveau succeeded in bridging the gap between sound mathematical formulations which require computationally expensive algorithms and the application of these methods to real-world problems in robotics. In particular the collaboration with an industrial partner like Airbus shows that the methods have a considerably high TRL level.

The works of Mr. Naveau have been published in several international conferences including the IEEE International Conference on Humanoid Robotics and the IEEE International Conference on Robotics and Automation, which belong to the most important conferences in the field of humanoid robotics. In addition one publication already appeared in the recently established journal Robotics and Automation Letters. This list of publications confirms that the works of Mr. Naveau have been well accepted by the scientific robotics community.

Overall I would rate the submitted PhD thesis of Mr. Naveau as a strong thesis. It should be emphasised that the results of his thesis have not only be shown theoretically or in computer simulations, but also by successful real-world experiments with a full humanoid robot.

Sincerely

Christian Ott