A reduced dynamic model for humanoid robots

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***Abstract*—A new model for walking that has the same dimensions as the 3D LIP model but keeps the underlying dynamics of the biped is proposed. The proposed model is called *essential model* and it can be written based on the internal states of the robot and external information, thereby generating models for different purposes. The main advantage of the *essential model* is that it allows to generate walking gaits that ensure that the Zero Moment Point (ZMP) is kept in a desired position or it follows a desired path while the gait is performed.**

***Index Terms*—Periodic walking gaits, modelling, virtual constraints**

I. Introduction

The modeling of humanoid robots with many degrees-of-freedom (DoF) can be done via the complete dynamic model. However, the complexity of the model can be an obstacle to well discern the essential factor of the walking. Another alternative is to simplify the model by neglecting some dynamical effects like in the 3D Linear Inverted Pendulum (LIP) model. Nonetheless the resulting walking gaits can make the ZMP evolving outside of the convex hull of support when they are replicated by the complete model of any humanoid robot. Therefore, complementary control techniques or adjustments must be taken into account. One of the main difficulties of walking studies is the equilibrium of the robot, i.e. to satisfy the contact hypothesis and in particular to avoid the rotation of the stance foot. Thus, the constraint on the Zero Moment Point (ZMP) is crucial. One way to ensure this constraint is satisfied is by using high-level control to impose a desired evolution for the ZMP.

The objective of this work is to propose a new model of the same dimension that the 3D LIP model that keeps the underlying dynamics of the biped robot, in order to develop walking gaits that deals with the issues described above. We have called this model: *essential model*.

The proposed model can be written based on the internal states of the robot and external information, thereby generating models for different purposes. When the walking gaits obtained with our model are performed by the complete dynamic system, the ZMP is kept in a desired location during the whole step, unlike the 3D LIP model case. In fact, it is possible to make the ZMP follows a desired path while the robot performs its motion. Even more, by using our model, impacts of the swing foot with the ground can be considered to find periodic walking gaits.

II. The *essential model* and simulation results

By using the humanoid robot ROMEO three different cases have been proposed to design our *essential model* in order to show its effectiveness.

A. Case I.

For the first case time trajectories are proposed to define the desired motion of the robot. No impact is considered and a fixed upper-body pose and fixed location of the ZMP is desired for all the step. i.e. $(p_{x,d}, p_{y,d}) = (0, 0)$ w.r.t. inertial frame attached to the stance foot. By considering a constant CoM vertical position, a comparison with the 3D LIP model is carried out. The result is shown in Fig. 1.

B. Case II and III.

For the second case virtual constraints are used to define the trajectories of the robot. Furthermore, an impact of the swing foot with the ground is considered to build an *essential model* where the upper-body and ZMP are kept in a fixed desired position as in the previous case.

For the third case time trajectories are proposed to define the desired motion of the robot. An impact of the swing foot with the ground is considered. Furthermore, an upper body motion and a desired trajectory for the ZMP is specified to be achieved during the step. The results of these two cases are shown in Fig. 2. A sequence of frames that shows the performance of ROMEO for two steps with the last case is shown in Fig. 3.

III. Conclusion

The *essential model* is developed by taking into account the whole dynamics of the robot and its simplification is based on the assumption of a good tracking of the reference motion. As a consequence, the resulting walking gaits always keep the ZMP in the desired path. Furthermore, impacts of the swing foot with the ground can also be considered in the development of walking gaits. Moreover, this model can conceivably be

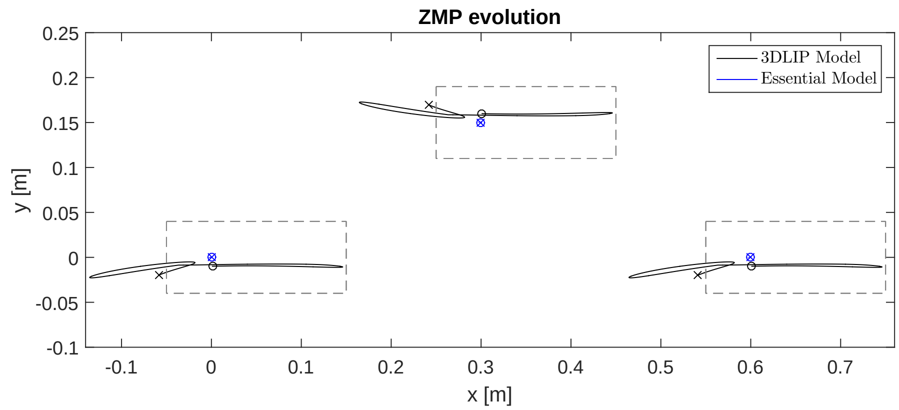

Fig. 1. Comparison of the evolution of the ZMP for the gaits obtained with the 3D LIP model and the *essential model* respectively. It is shown how the gait obtained with the *essential model* makes the ZMP be kept in the desired location during all the walking gait. The circles and crosses denote the initial and final points of the ZMP respectively.

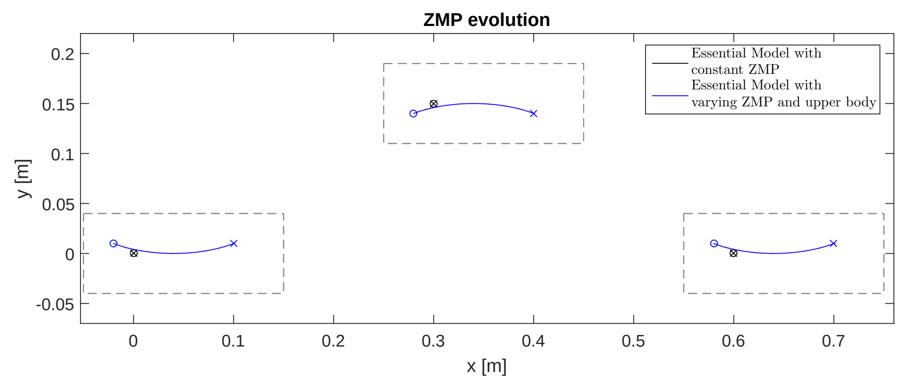

Fig. 2. Comparison of the evolution of the ZMP for the gaits obtained with the *essential model* for the second and third cases. It is shown how the obtained gaits ensure the ZMP stays in the desired location or follows the desired path during the walking gait. The circles and crosses denote the initial and final points of the ZMP respectively.

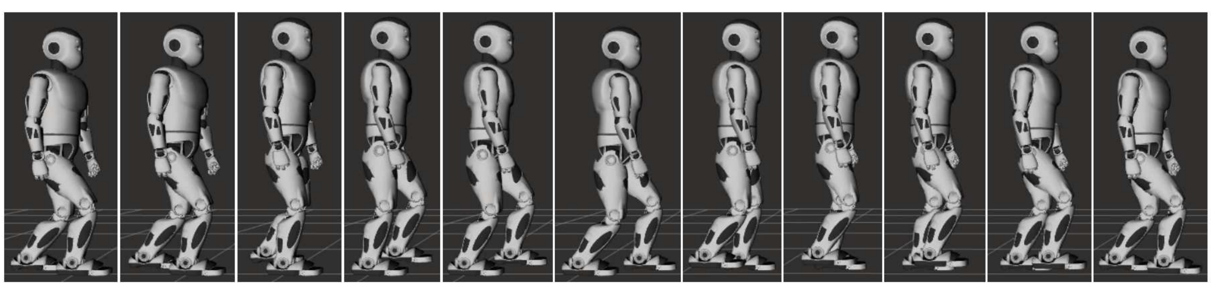

Fig. 3. Sequence for two steps performed by ROMEO with the *essential model* for the third case.

used to develop motions in double support phases. However, this work, only sets the basis for further research in order to achieve walking gaits with better performance. Some future works on this issue are:

- Exploiting this model for the motion of the robot during double support or multi-contact phases.
- Introducing optimization to the upper body motion in order to reduce the joint torques.
- Proposing human-like trajectories for the ZMP in order to develop more efficient walking gaits.
- Introducing different external information to define the desired trajectories of the robot, not just the time. This external information could be the CoM of other robots in order to achieve walking synchronization among robots, or joysticks to handle the motion of the robot as a function of them, etc.