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On a class of biped underactuated robot models with upper body: Sensitivity analysis of the walking performance

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1. Introduction

Biped underactuated robots with an upper body (being a torso) form a subclass of legged robots. This study deals with the walking performance of such class of legged robot models and has been motivated by the need to implement of the previously developed sensor and control algorithms for the real-time movement of the laboratory walking robot, designed and built at the Department of Control Theory of the Institute of Information Theory and Automation (ÚTIA) of the Czech Academy of Sciences, see Fig. 1 (left). A detailed description of this underactuated walking-like mechanical system (called further UTIA Walking Robot – UWR) is provided in [2] and [5]. The simplest underactuated walking robot hypothetically able to walk is the so-called Compass gait biped walker, alternatively called the Acrobot, see Fig. 1 (right). For a review of underactuated mechanical systems, i.e. systems with fewer actuators than degrees of freedom, which encounter many applications in different fields (e.g., in robotics, in aeronautical and spatial systems, in marine and underwater systems, and in-flexible and mobile systems), see [3].

As follows, we examine the walking performance of parametrized models for different walking regimes and different values of model parameters. More specifically, the sensitivity analysis (i.e., parameter study) of the walking performance with respect to certain design variables (model parameters) is carried out using the software package *alaska/MultibodyDynamics*. The main attention is attracted to the role of the upper body mass m_3 and position l_{c3}, see Fig. 1 (right).

Last but not least, having surveyed the mechanics of planar biped robots, our subsequent goal is the analysis of a 3D biped model where lateral balance is either controlled, suppressed or compensated.

2. Model formulation

The robot model, see Fig. 1 (right), is planar, with two rigid massless legs of length l_l, i.e., with pointmasses (scaled masses $m_1 = m_2 = m_f = 0.1$) as feet (where scaled lengths $l_{c1} = l_{c2} = l_l = 1$), a finite pointmass (scaled mass $m_3 = 0.3$) at the hip joint (pelvis). Moreover, the upper body (a scaled pointmass $m_b = 0.7$) is connected via a rigid, massless stick (of scaled length $l_{c3} = 0.4$) to the hip joint, see Fig. 1 (right). There are two degrees of freedom mechanism for one pair of legs without knees, ankles and feet actuated only in the hips. Moreover, an additional

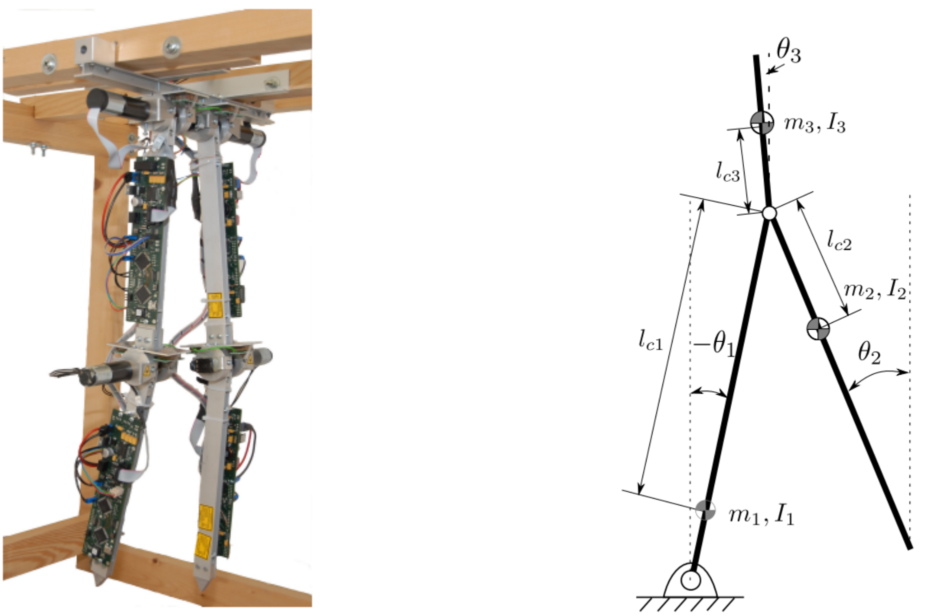

Fig. 1. (*Left*) UTIA Walking Robot: laboratory mechatronic walking robot-like system – immobile until now; (*right*) Compass gait biped walker with upper body: parameters and coordinates

(third) link is representing a torso (within the pelvis) in the human body description. Thus, there are 3 planar links in form of rigid sticks with pointmasses at the end and one degenerated point-like link of scaled mass $(1-m_b)$ which connects all 3 stick-like links together. As it was already mentioned, the mass and length parameters are dimensionless. The mass scaling is done using the total mass (pelvis + upper body), for the length scaling is used the leg length l_l.

Furthermore, it is convenient to introduce two actuated hip joints, i.e., the upper body (the torso) is not actuated. For instance, for sake of simplicity, the upper body position described by the angle θ_3 undergoes the kinematic coupling, modelled as simple as possible, i.e., the third link with upper body mass dwells in midway between the two legs

$$\theta_3 = \frac{\theta_1 + \theta_2}{2}\,. \tag{1}$$

The above restriction (1) makes the Compass gait system fully actuated and represents a starting point to more complex ones.

3. Walking performance

As it was stated in the Introduction, we aim to study the walking performance of our model for different walking regimes and different values of upper body length. This sensitivity analysis is carried out using the software package *alaska/MultibodyDynamics* [1]. The energy consumption of the model is usually represented in the non-dimensional form of specific resistance, which is defined as the energy consumption per distance traveled per kilogram mass per gravity, see [4] and references within there.

For the previously computed trajectories, we perform numerical simulations on a robot model derived from the software package *alaska/MultibodyDynamics*. Afterwards, we solve the corresponding torques at both hip joints (based on the D'Alembert principle). Finally, for this relatively simple case of a bipedal robot walking in two dimensions, we calculate how the cost functional, being the specific resistance, depends on the upper body length.

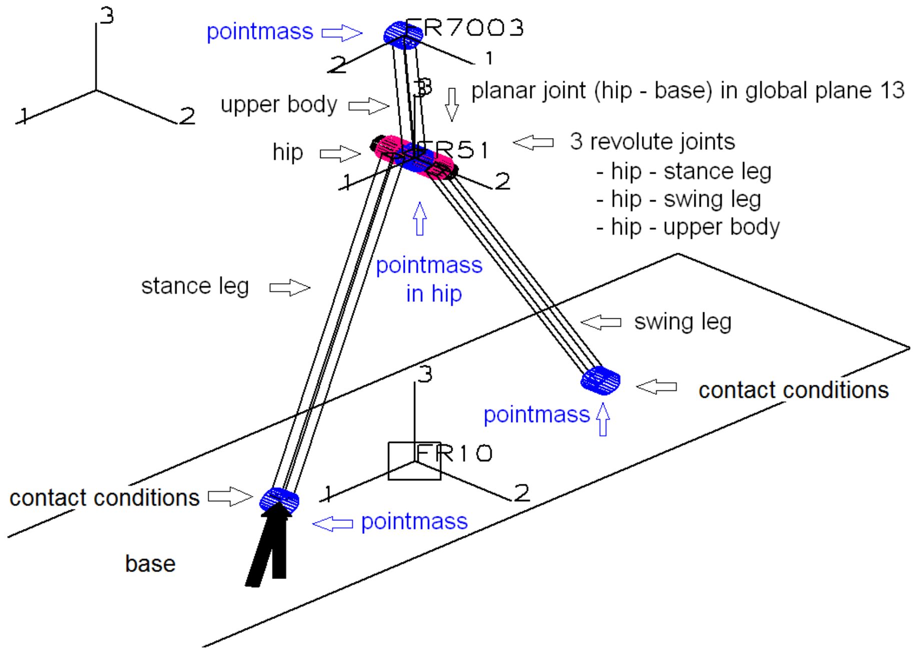

Fig. 2. Visualization of the Compass gait biped walker (with the description of kinematic joints) by Alaska 2.3 simulation tool

4. Conclusions

In this work, using the Alaska simulation tool, we studied the sensitivity of the walking performance of a class of biped robot models with respect to the upper body length. Encouraged by the successful implementation of the model kinematics, the analysis of system dynamics is conceived for the near future. In this way, we are open to the possibility of running a similar study concerning the robot model stability, or more precisely, to describe the stability of the walking for different upper body lengths. Here, the expected result is to find in some sense optimal realisation of the robot geometry for a specific walking regime. The optimization of both the robot geometry and walking regime (distribution of the torque to be applied into actuators at the hip) are left for a future publication.

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