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Cross four-bar structure for the knee of a bipedal robot.

Arnaud Hamon*, Yannick Aoustin*

*IRCCyN UMR 6597, Ecole Centrale de Nantes, Université de Nantes, CNRS, 1 rue de la Noë, BP 92101, 44321 Nantes Cedex 3, France.
e-mail: arnaud.hamon@irccyn.ec-nantes.fr, yannick.aoustin@irccyn.ec-nantes.fr

1 Introduction

The objective of this work is to propose a more efficient joint for the knee of a bipedal robot. Indeed, the biomechanical studies proved the human knee joint is a complex structure which allows a rolling and a sliding movement of the femur on the tibia in the sagittal plain [1]. These movements are guided by the cruciate ligaments and the articular contacts [2]. These motions cannot be reproduced by one or two revolute joints. In [3], authors introduced polycentric knee joint with a four-bar structure to approach the human knee movements. A cross four-bar knee with respect to a revolute knee joint can reduce the energy consumption of a biped, see [4]. Moreover, several papers paid interest to the effect of spring equipping the bipedal robot joints [5].

We compare the performance of a bipedal robot which uses cross four-bar linkages on the knee joints and we compare the energy consumption of this biped during a walking gait with and without springs on the knee joints. We develop an optimization problem to design optimal walking trajectories with and without springs on the knees. These sets of optimal trajectories show the benefit of springs on the energy consumption for the bipedal robot with cross four-bar knees.

The considered biped is presented on Fig.1. The cross four-bar is depicted on Fig. 2. The actuated joint is equipped of a spring. The stiffness coefficient k of the spring can be chosen for a desired walking velocity.

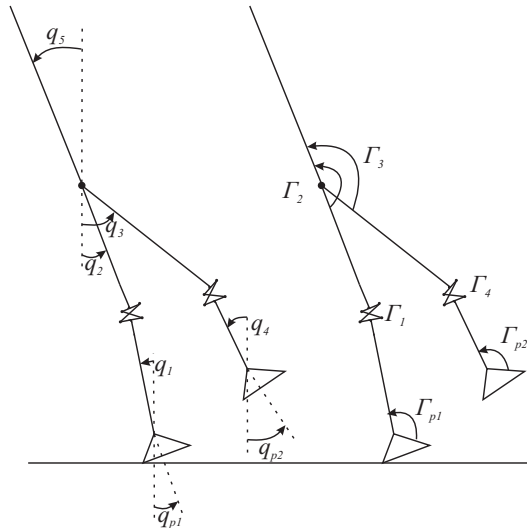


Figure 1: Diagram of the planar bipedal robot. Absolute angular variables and torques.

The objective of this work is to design a set of cyclic reference trajectories on a speed range to compare the energy expenditure of the bipedal robot, with and without springs on the knee joints, during a walking gait.

Figure 2: Details of the four-bar linkage with spring on the actuated joint α_1 .

Each step is composed of a single support phase, where the stance foot is in flat contact with the ground, and an impulsive impact.

To design a walking trajectory, we prescribe the trajectories of each joint of the biped by a cubic spline function with only one knot. This choice allows us to fix initial and final positions and speeds and an intermediate position for each joint. 30 unknown variables are necessary to compute a walking trajectory.

The properties of the impulsive impact give the initial velocities of each joint in function of their final positions and velocities that reduces of 6 the number of unknowns to design a gait. The cyclicity of the trajectories gives the initial positions in function of the final positions that reduces of 6 the number of unknowns. We can compute the final positions of each joint from the final position of the trunk and the length of the step by solving of the inverse geometric model. Finally, we can compute a walking trajectory with 4 variables of configurations, with 6 final velocities and with 6 intermediate positions.

To obtain these 16 variables, we solve, with a SQP method, a parametric optimization problem under constraints to respect the conditions of validity of the gait, such as the unilateral constraint of the biped with the ground, to ensure that the movement is realistic. The criterion of the optimization problem is :

$$C_{\Gamma}(x) = \frac{1}{d} \int_0^{t_f} \Gamma^T \Gamma dt. \quad (1)$$

The walking trajectories optimization for a bipedal robot with springs on the knee joints is quite similar than a biped without springs. The difference is on the computation of the articular torques. Indeed, we need to take into account additional torque provided by the spring which depends on the stiffness coefficient of the spring and the position of the knee joint. Moreover, in the definition of the parametric optimization problem we use an additional variable which is the stiffness coefficient of the spring.

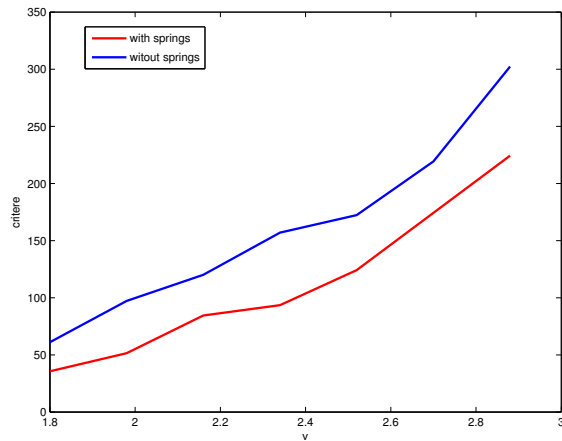


Figure 3: Energy consumption of the biped in function of the velocity with and without springs.

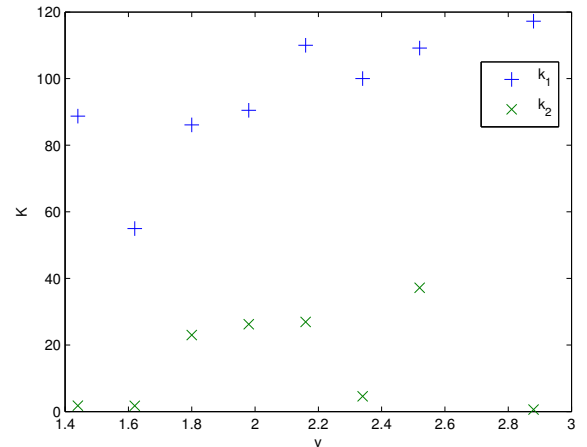


Figure 4: Energy consumption of the biped in function of the velocity with and without springs.

2 Results

With the sets of reference trajectories obtained for the bipedal robot with and without springs on each knee joints, we can compare the energy consumption of the biped in function of the walking velocity. Fig. 4 shows that the springs on the knee joints reduce the energy consumption of the biped during a walking gate.

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