Using the Generalized Inverted Pendulum to generate less energy-consuming trajectories for humanoid walking

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Abstract

The Generalized Inverted Pendulum model (GIP) describes human normal walking from the external forces point of view. Its characteristics include a pivot point under the ground level, in opposition to all other inverted pendulum models (for robot control or human motion) with a pivot point at ground level. This work uses Sakka's GIP model [4], initially proposed to model human walking, to generate a more human inspired walking pattern of humanoid robots. We first show that the differential equations describing the inverted pendulum dynamics do not change whether the pivot point is located under the ground or at ground level. Then, we show that the use of a pivot point under the ground considerably reduces the energy consumed during the gait. Finally, we explain the constraints on the solution in order to obtain appropriate 3D trajectories for bipedal walking.

A classical way to generate humanoid walking gait is based on the linear inverted pendulum (LIP) [2]. The LIP model is composed of a prismatic massless rod linking the robot center of mass (CoM) to its Zero Moment Point (ZMP). The pendulum rod rotates around the ZMP used as a pivot point. The controlled CoM then follows a horizontal linear trajectory, and the dynamics of the pendulum can be solved analytically as the CoM keeps a constant height while walking. As was shown in previous works, the LIP model is far from leading to a low energy consumption behavior. First, considering the vertical motion of CoM is advised [3]. Second, it was suggested by McGeer [1], then proved by Sakka *et al.* [4], that the human motion indeed behaves as an inverted pendulum but with a pivot point located under the ground level (GIP). Based on these observations, we wish to determine a more human-like humanoid walking with lower energy cost than current approaches.

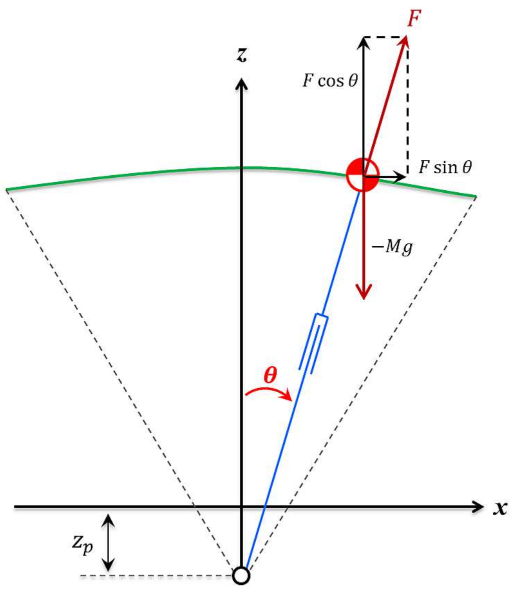

Figure 1: Generalized inverted pendulum in the sagittal plane.

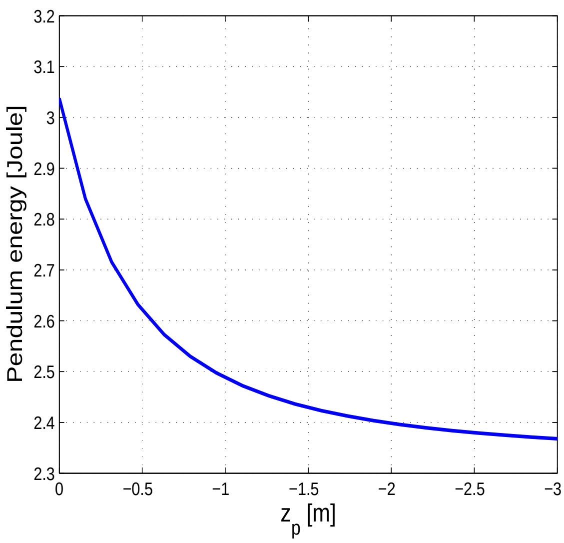

Figure 2: Pendulum energy as a function of z_p.

Our GIP model is illustrated in Fig. 1. Where F is the force driving the CoM, M is the robot mass, g is the gravity acceleration, z_p is the vertical component of the pivot point. We have calculated the energy of the pendulum as a function of z_p for many values of each walking parameters: step length L, step width

L_w, step period T and mean height of CoM z_0. We have found in all cases that the energy consumed by the system decreases as the pivot point goes further under the ground. Fig.2 shows the evolution of the energy as a function of z_p for the case $(L = 0.2\ [m],\ L_w = 0.2\ [m],\ T = 0.6\ [s],\ z_0 = 0.6\ [m])$. We notice that the lower the position of the pivot point in the ground, the lower the cost. We can see that the energy is reduced by 20% when $z_p = -1.55$ [m] compared to the case $z_p = 0$. Between -1.55 and -3 [m], the reduction is negligible. But the choice $z_p = -1.55$ [m] is not possible because a great value of zp leads to an unrealistic size of foot. Fig.3 illustrates the GIP in the sagittal plane with the rods at the beginning and at the end of the step. We consider many values of z_p between 0 and -1 [m], the foot is represented by a bold green line. We notice that the center of pressure (CoP), or the intersection between the rod and the ground level ($z = 0$), approaches the foot boundaries when z_p goes farther under the ground, so we need a big foot to maintain the balance. For a given foot size, we define the stability zone between x_1 and x_2 as a percentage of the foot length. We suppose that the CoP must stay inside the stability zone while walking. The foot width gives y_1 and y_2, the boundaries of the stability zone along the transversal axis (y). The stability boundaries along x and y give us the good choice of z_p. Fig.4 shows the pendulum in two cases: the red one corresponds to the case $z_p = 0$ and the blue one corresponds to the case $z_p < 0$. The feet are represented by green rectangles situated in the horizontal plane (z=0) and the stability zone is represented by the black rectangle inside each foot. We notice here that the blue pendulum respects the stability zone, because its rod passes through the stability zone during the entire motion.

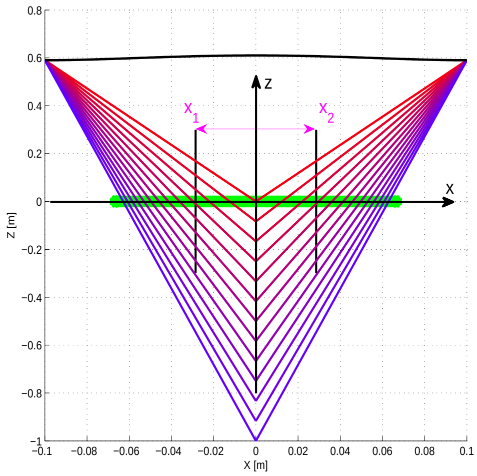

Figure 3: The inverted pendulum in the sagittal plane

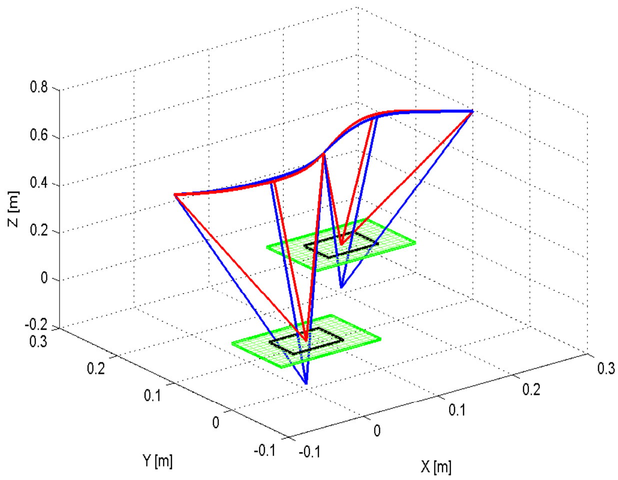

Figure 4: 3D view of the pendulum.

References

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