# LOCOMOTION CONTROL OF PASSIVE DYNAMIC WALKERS BASED ON INTERNAL ENERGY

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## 1. INTRODUCTION

The compass model is a simple locomotion model composed of two leg segments connected through a hip joint. In [2] it is shown how this robot is able to exhibit a stable walk along a slope using its natural dynamics. Unfortunately, this is strictly bounded to the initial conditions, the mechanics of the robot and the kind of slope.

In this work we propose a simple control strategy based on energy control. By observing human locomotion one can see how the mechanical energy is on average constant and continuously turns between kinetic and potential (gravitational and elastic). Assuming that a human walks with a constant energy and considering purely elastic collisions the total energy is preserved and a stable walk can be obtained. Unfortunately in the real world collisions are not purely elastic and usually lead to certain energy drop. Starting from these observations this paper proposes an under actuated control strategy based on energy shaping which is able to achieve a stable walk both on slopes and horizontal ground. The underlying idea is to stabilize the system internal energy implicitly leading to recover the energy lost on impacts. The actuation acts on a single rotational joint placed at the hip.

## 2. IMPLEMENTATION

The considered mechanical design is derived from the Compass model defined in [1]. The total mass of the robot is concentrated in three points: $m_h$ 1 kg, at the hip, $m_l$ 1 kg for each leg at the distance of $b$. The legs have the same total length equal to 1 m, subdivided in two equal segments of 0.5 m $l = a + b$. We propose the following energy-based control law:

$$\tau_h = k(E - E_{ref})\dot{q_h}$$

where $q_h$ is the generalized coordinate of the hip joint and $E$ is the total energy of the system, $E_{ref}$ is a target energy and $k$ is a tunable positive constant. In the following we show by simulations how this simple control law is able enhance limit-cycle stability robustness while recovering the energy dissipated during impacts with the ground. To test the robot in realistic conditions we use Matlab and Drake frameworks [3]. To avoid the clearance problem arising when the robot leg switch from the flight phase to the stance phase we add two prismatic joints (see Figure 1) and a PD controller is implemented on such joints. The target position is evaluated as function of the angle between the two legs as follow

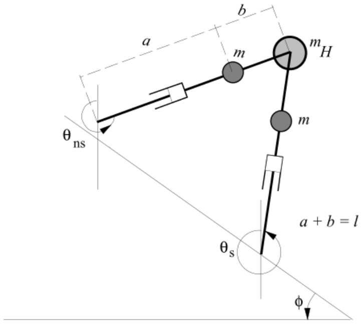


**Fig. 1**: Compass model on a slope with prismatic joint along the legs.

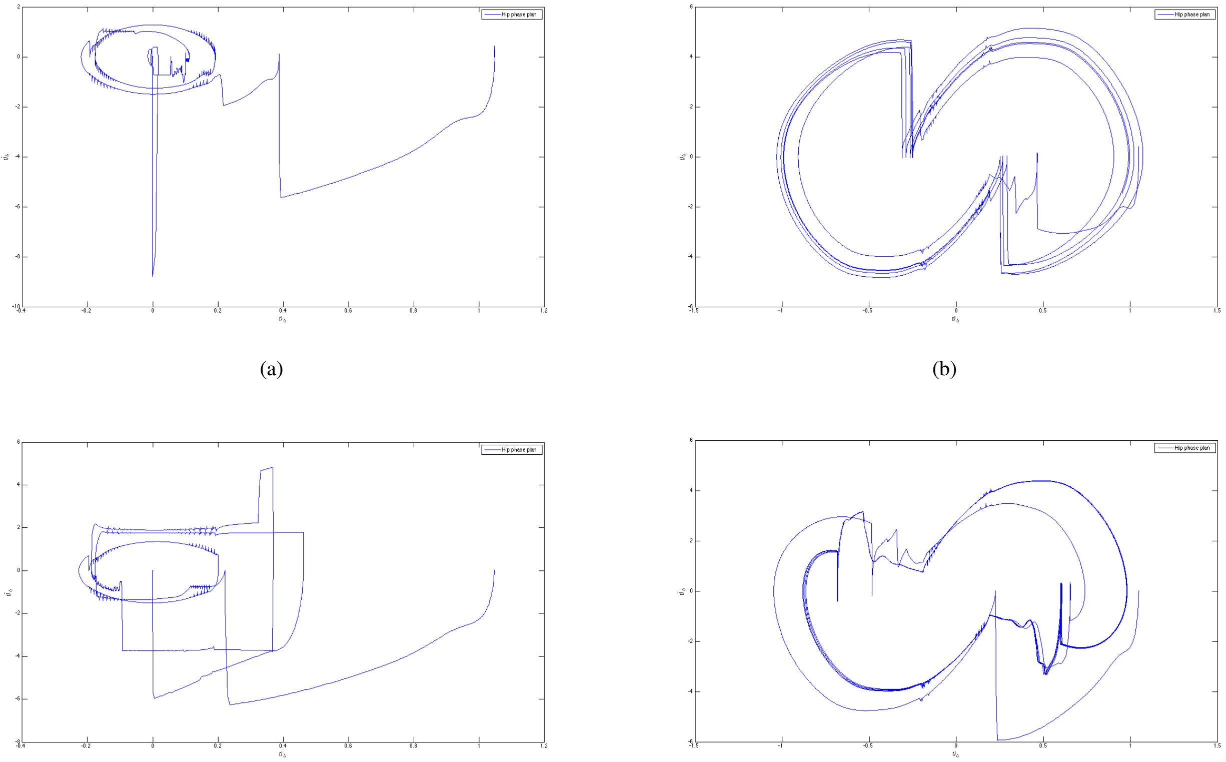
$$q_{ref} = d_r e^{-\frac{\dot{q}_{leg}^2}{2(\frac{th}{3})^2}}$$

where $d_r$ is the desired retraction offset, $th$ is the angle threshold. The exponential term provides a soft trajectory preventing shock during the retraction.

## 3. RESULTS

Figure 2a and 2c shows the limit cycle of the non controlled compass robot on horizontal and sloped planes. In the case of ground walking, each time the leg impacts with the ground a loss of energy occurs causing smaller concentric orbits until the robot falls to the ground. In the case of sloped plane, even starting from (properly chosen) good initial conditions small perturbations (mainly due to numerical approximations) cause the walker to fall dawn after some steps.

Figure 2b and 2d shows the limit cycle of the compass robot using the proposed energy controller on horizontal and



(a)

(b)

(c)

(d)

**Fig. 2**: (2a) Limit cycle of a non controlled robot on a horizontal surface; (2b) Limit cycle of controlled robot on a horizontal surface $E_{ref} = 26.5J$; (2c) Limit cycle of a non controlled robot on a sloped surface; (2d) Limit cycle of a controlled robot on a sloped surface $E_{ref} = 26.72J$.

sloped planes, respectively. One can see that our controller allows good convergence of the trajectory around a limit cycle both in the case of slope and horizontal ground. The shape of the curve is almost symmetrical with strong decelerations due to impacts with the ground. See experiment video at *https://youtu.be/qG1WGr6o7Es*

## 4. CONCLUSION

This abstract showed the feasibility of using a simple energy controller for enhancing the limit cycle robustness of a compass walking robot. During simulations the system showed improved robustness with respect to the non controlled robot and allows walking on an horizontal plane. We highlight that the energy control concept can be principle extended to other kind of passive dynamic walker such as slip or multi articulated model.

We also highlight that the successful application of the proposed control scheme is still dependent on the initial conditions of the robot which must be sufficiently close to the natural limit cycle. To overcome this limitation, we are planning to use reinforcement learning techniques and adaptive control to search for optimal parameters $k$ and $E_{ref}$ which can possibly be state-dependent.

## 5. REFERENCES

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