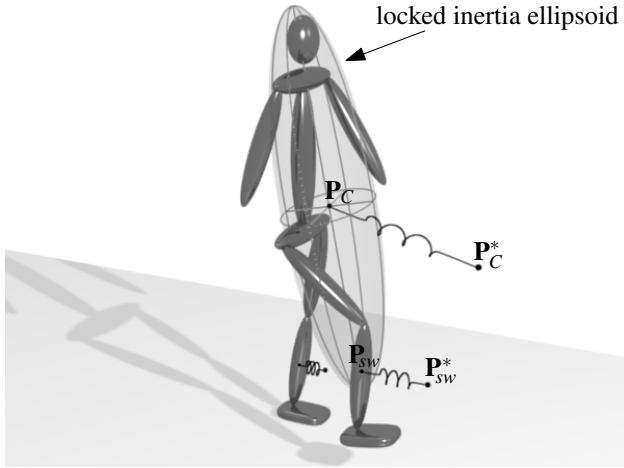


# Control of walking robots using virtual springs

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**Figure 1:** Virtual springs attached to the walking robot. For clarity, distance between  $\mathbf{P}_C$  and  $\mathbf{P}_C^*$  is exaggerated.

## SUMMARY

In this abstract our progress in walking algorithms is discussed. We try to achieve robust and energy-efficient walking by using controllers based on virtual springs.

## INTRODUCTION

In our search for robust and energy efficient control of walking robots, we are making extensive use of simulation. In order to facilitate the development of algorithms, we want to design controllers that work in a space of “meaningful variables”; *i.e.*, we don’t control joint angles directly but we control things as “position and velocity of center of mass”, “shape of the robot’s locked inertia ellipsoid” [1] and “foot position”.

## CONTROLLER

We propose a controller for a 3D bipedal robot, based on virtual springs [2]. The idea of a virtual spring is to exert torques on all joints of the robot (called *equivalent joint torques*,  $\tau$ ) in such a way that the robot behaves as if a spring were attached to it.

Instead of attaching the virtual spring (which we actually model as a damped spring with  $K$  and  $D$  as spring and damping constants respectively) to any of the robot’s links, we connect it to the center of the inertia ellipsoid of the whole robot, called  $\mathbf{P}_C$  (see figure 1). This results in some parts of the system accelerating in such a way that the center of the inertia ellipsoid moves as if it were pulled by the virtual spring.

The other end of the spring is attached to a point in space,  $\mathbf{P}_C^*$ , which follows a periodic trajectory. Eventually, in our search for a robust and energy efficient controller, this trajectory will be subject to optimization. In this set-up, the virtual (3D) force  $\mathbf{F}_C$  exerted by the virtual spring can be

calculated by

$$\mathbf{F}_C = K \cdot (\mathbf{P}_C^* - \mathbf{P}_C) - D \cdot \frac{d}{dt} (\mathbf{P}_C^* - \mathbf{P}_C). \quad (1)$$

Assuming that at least one foot has full contact with the floor, the equivalent joint torques  $\tau$  are

$$\tau = J^T(q) \cdot \mathbf{F}_C, \quad (2)$$

where  $J(q)$  is the the jacobian matrix mapping joint velocities to the velocity of the robot’s center of mass, *i.e.*,  $\dot{\mathbf{P}}_C = J(q) \cdot \dot{q}$ . In the more general 6D case, where  $\mathbf{F}_C$  is replaced by a wrench  $\mathbf{W}_C$ , the way to proceed is similar, although some extra mathematical steps are needed.

The legs of the robot are also controlled through virtual springs (as shown in figure 1); proper foot placement is achieved by dynamically adjusting the end point  $\mathbf{P}_{sw}^*$  of the swing-leg spring.

This strategy would work perfectly if the allowable torques in the joints were unlimited. Unfortunately, the ankle torques of the stance foot are severely limited: a too large torque will inevitably make the stance foot rotate around one of its edges, thereby losing the full contact with the floor. The maximum allowable ankle torque,  $\tau_{\text{ankle,max}}$  is dependent on the foot size and the state  $(q, \dot{q})$  and actions  $(\ddot{q})$  of the robot (in particular, on the amount of pressure exerted on the foot).

The limitation in allowable ankle torque leads to an equivalent limitation in allowable  $\mathbf{F}_C$ . Therefore, the actually implemented virtual force is linearly scaled down by factor  $0 \leq \alpha \leq 1$  such that the ankle torque (one of the elements of  $\tau$ ) stays within the allowable range. This force may not be enough to keep the robot upright, which is actually the reason that walking robots have to take steps at all. In this sense, the best spot to place the swing foot is the spot where the allowable  $\mathbf{F}_C$  is maximized.

## CONCLUSION

The proposed controller needs some more detailing before it can actually make the robot walk in simulation. For example, determining where exactly to place the foot has not been considered yet. We are working on this, and expect to show the results soon.

## REFERENCES

- [1] G. van Oort and S. Stramigioli, *Geometric dynamics analysis of humanoids – locked inertia*, Benelux meeting, 2008.
- [2] J. Pratt, *Virtual Model Control of a Biped Walking Robot*, Massachusetts Institute of Technology, 1995.