An efficient orientation and center of mass based bipedal balancing engine

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Balancing a bipedal robot across different motions is one major challenge in the RoboCup 3D Simulation. While movements are usually modelled in the robot's local coordinate frame, adapting all calculations to the current situation is a complex and time-consuming task, which has to be solved for each motion separately. This paper describes the balancing engine used by the magmaOffenburg 3D simulation team to implicitly balance different two legged movements, such as walking. The engine is based on the current orientation and center of mass of the robot, which together with an intended leaning direction result in a dynamic adjustment of the position and orientation trajectories of the limbs specified by the actual behavior.

A robot motion can by defined in many ways. When using inverse kinematics, one automatically has to decide for a reference frame for calculations. The obvious choice for the robot's torso as reference frame suits well for the purpose of IK calculations. However, with respect to balancing motion definitions such as walking, the torso as a twisting system lacks the adaptation to the robot's current tilt (x- and y-rotation) and thereby as well to its center of mass, as shown in figure 1.

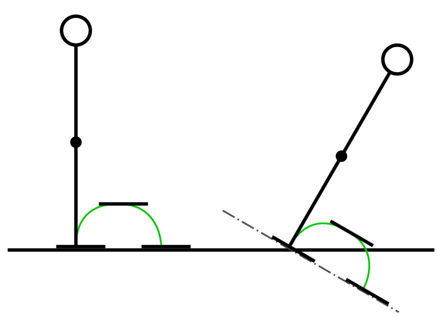

Figure 1: Local defined motions do not adapt to the current tilt and CoM of the robot

Extending the trajectory interpolations of the motion models to also cope for the current situation can be very complex and counter intuitive to the basic calculations. Moreover it has to be done for each motion separately and makes testing and debugging of those calculations even more difficult.

The balancing engine described in this paper addresses this issue by the introduction of a virtual reference frame. Motion trajectories defined in this frame are then automatically adapted to the current situation during execution. This way motion definitions keep as simple as in the local case, but implicitly gain the power of dynamic situation adaption.

The idea behind the balancing engine follows a simple thought: A balanced motion should always support the center of mass. In order to achieve this, motions should be defined with respect to a reference frame with the center of mass as its origin. Furthermore supporting the center of mass means acting against the gravity, regardless of the actual tilt of the robot. The orientation of the reference frame should therefore always be upright, but still facing the topview view direction of the robot.

So far we simply switched the reference frame in which we define the motions from the local torso frame to a virtual reference frame. In order to use an inverse kinematics solver, we now need to transform the motion trajectories back into the torso frame.

So far movements are closed-loop in the sense that trajectories of legs are adjusted to any leaning of the torso or movement of the CoM. However they are not counteracting any leaning of the robot. This is done in a second closed-loop adjustment of the motion trajectories to continuously push the current local z-axis towards the intended leaning direction. This can be adjusted between 0% (no adjustment) and 100% interpolation (fully adjust to the intended leaning).

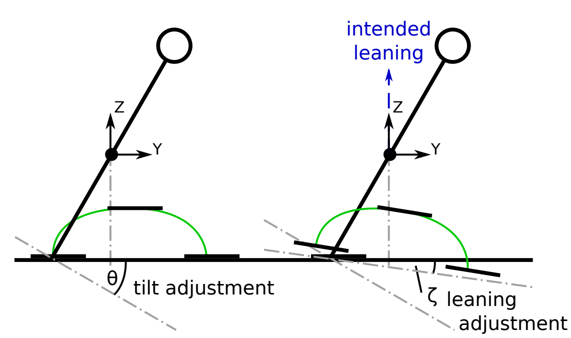

Figure 2: An automatically adapted motion defined in the virtual reference frame. Note that the motion definition in this figure is also partly dynamic, by taking the initial foot position into account.