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Late Breaking Report.

Real-Time Footstep Planning with CoM Dynamics

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***Abstract*— We propose a search-based footstep planner that considers the robot dynamics during planning. It generates collision-free and dynamically feasible paths in real-time in cluttered environments. Thus, the planner handles explicitly disturbances that affect the walking stability such as pushes.**

I. Introduction

Many balance control frameworks such as [1], adjust step placement and timing to counteract strong perturbations without considering the environment, which may lead to collisions. On the other hand, recent footstep planners such as [2] and [3] have been able to successfully generate 3D footstep sequences for complex unstructured environments. However, they do not consider CoM dynamics and report failures in executing footsteps due to balance errors [2]. Lin et al. ([4]) propose a planner including CoM dynamics but it lacks real-time capabilities. In our work, we combine A^*-based adaptive footstep search (similar to [3]) with the capture step framework [1] to obtain a real-time footstep planner that considers CoM dynamics.

II. Method

In contrast to [3], no precomputed reachability map is used to determine possible foot placements. We dynamically compute step size constraints based on the current CoM state and propagate the CoM dynamics through the search tree. To meet real-time constraints even in complicated environments, we propose a hierarchical planning system. First, a global footstep sequence towards the goal is generated. Then, after each support exchange, the next steps are replanned locally.

A. Footstep Search

During each iteration of the A^* algorithm, we expand the current node as follows: first, we compute the set of reachable CoM positions $\mathcal{C}_{pos} = [c_x^-, c_x^+] \times [c_y^-, c_y^+]$ and velocities $\mathcal{C}_{vel} = [\dot{c}_x^-, \dot{c}_x^+] \times [\dot{c}_y^-, \dot{c}_y^+]$ based on ZMP limits and the linear inverted pendulum model (LIPM). We then predict the region of possible footsteps $\mathcal{F} = [f_x^-, f_x^+] \times [f_y^-, f_y^+]$ using the capture step framework [1]:

$$f_x^{\pm} = \frac{\dot{c}_x^{\pm}}{C} \tanh(C\tau) + c_x^{\pm}, \quad f_y^{\pm} = \pm C\sqrt{\left(\frac{\dot{c}_y^{\pm}}{C}\right)^2 + \alpha^2} + c_y^{\pm}, \tag{1}$$

whereas C is the LIPM constant, τ describes the half stepping time and α denotes the minimum lateral distance between the CoM and the supporting leg. Finally, we apply the adaptive footstep search from [3] to $\mathcal{F}$ to generate the subset of neighbor footsteps $\mathcal{F}'$.

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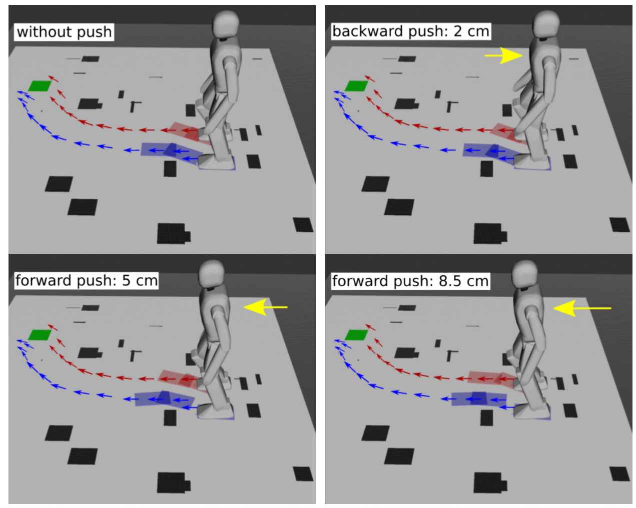

Fig. 1. Our footstep planner reacts to pushes. The green square denotes the goal. The global path is depicted by arrows while the local plan is depicted by rectangles. Top: no disturbances (left) and a backward push resulting in a CoM movement of 2 cm. Bottom: forward pushes resulting in CoM movements of 5 cm (left) and 8.5 cm (right). Note how the local steps change according to the robot stability.

B. Propagation of the CoM Dynamics

Since the next CoM position and velocity depend on the known current state and the unknown ZMP offset, the latter can be inferred by Eq. (1) and be used to predict the next CoM state for each footstep $(f_x, f_y) \in \mathcal{F}'$.

III. Experiments

We evaluate our approach in simulated cluttered environments. The planning region has a size of $3 \times 3\,\mathrm{m}$ and a resolution of 1 cm. Figure 1 shows how the footsteps are adapted to compensate the effect of the pushes. Note that there is an obstacle in front of the left foot. Traditional balance control frameworks would increase the sagittal step size for the left foot to recover from a push from behind, which would lead to a collision. Our method considers the environment when adapting the step size and thus successfully avoids collisions.

References

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