Real-time Walking Path Planning with 3D Collision Avoidance

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***Abstract*— We illustrate an original real-time replanning scheme experimentally for humanoid robot reactive walking. Footsteps are planned as a sequence of "half-steps" that can be easily integrated with randomized planning methods such as RRT. Combined with an approximation of the volume swept by the robot legs during dynamic walking, our method is able to cope with the collision avoidance for 3D obstacles while maintaining real-time computation. We experimentally validate our approach on the robot HRP-2.**

I. Introduction

In order to achieve real-time navigation in dynamic environments, humanoid robots need robust and reactive planning capacity of generating precise leg motions in a short amount of time. The dynamic and stability constraints intrinsic to humanoid locomotion make the problem of trajectory (re)planning particularly difficult to solve in real-time.

There have been not so many studies on real-time humanoid motion planning in dynamic environments due to its complexity of the problem. Here we consider moving 3D obstacles and handle the collision avoidance with the legs in an accurate way, based on fast motion planning with precomputed dense swept volumes [1]. We have developed real-time planning and replanning system with the humanoid robot HRP-2 in an environment where obstacles are tracked.

II. Real-time planning scheme

Planning is performed based on the scheme shown in Fig. 2 that allows planning and execution in parallel [2].

In an execution thread, the planned trajectory is sent to the control part. If collisions are detected along the planned path, a query is sent to trigger replanning to search a new collision-free path without suspending the execution.

To cope with asynchronous frequencies of planning and control loops, the controller uses a buffer to handle the large vectors sent by the planner. This buffer contains a lower body motion sequence $\phi_{lower}(t)$ that contains lower body joint trajectories of $\mathbf{q}_{lower}$, CoM and ZMP. This buffer is updated every time a new trajectory is received from the planner. Then the whole-body motion $\mathbf{q}$ unifying $[\mathbf{q}_{lower}, \mathbf{q}_{upper}]$ is sent to the controller.

The robot control and stabilization is performed using generalized inverse kinematics "Stack of Task" ([3]). The Stack of Task mechanism resolves different tasks such as trajectory of legs or CoM with priorities, and generates the whole-body motion $\mathbf{q}$ sent to the low-level controller of the robot.

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III. Walking path planning

A. Walking Pattern Generation based on "Half-Steps"

When a humanoid robot walks dynamically, a step has always some influence over the next step, and as a consequence it is not possible to easily modify the sequences of steps for they are not independent. We adopt a walking pattern generation method using "half-steps" [4] that can avoid this problem. The generation of dynamic walking motion is split into two phases.

First, we generate a walk with zero speed in the middle and at the end of each step. The generated walking path is thus composed of "half-steps" that can be concatenated at will. These half-steps are all dynamic trajectories, but with zero speed connections. It is therefore possible to stop the robot at the end of any half-step, either in double support or single support with the swing foot in maximum height.

In the second phase the half-steps are progressively merged by overlapping them. As a result, the motion becomes dynamic and smooth whereas the steps become interdependent. After the smoothing, very quick collision checking is performed with a similar approach as [1] where swept volume approximations are precomputed offline.

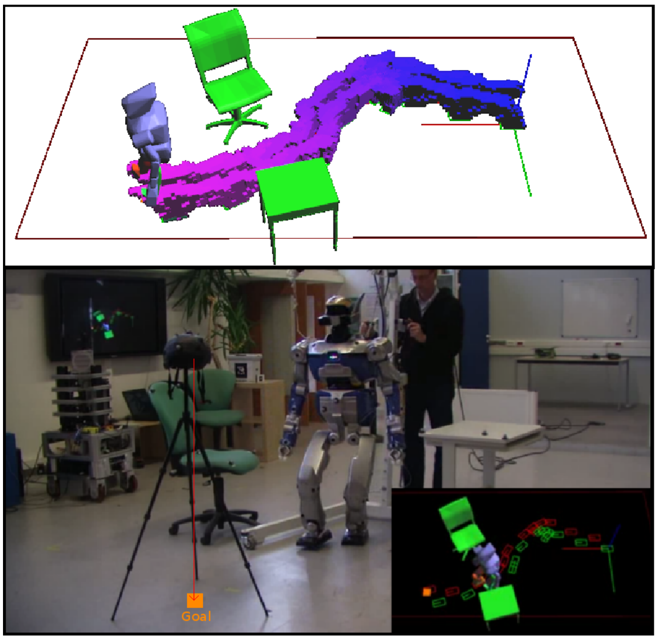

Fig. 1. Top: precomputed swept volumes are used to speed up collision detection for the legs. Bottom: experiment on HRP-2.

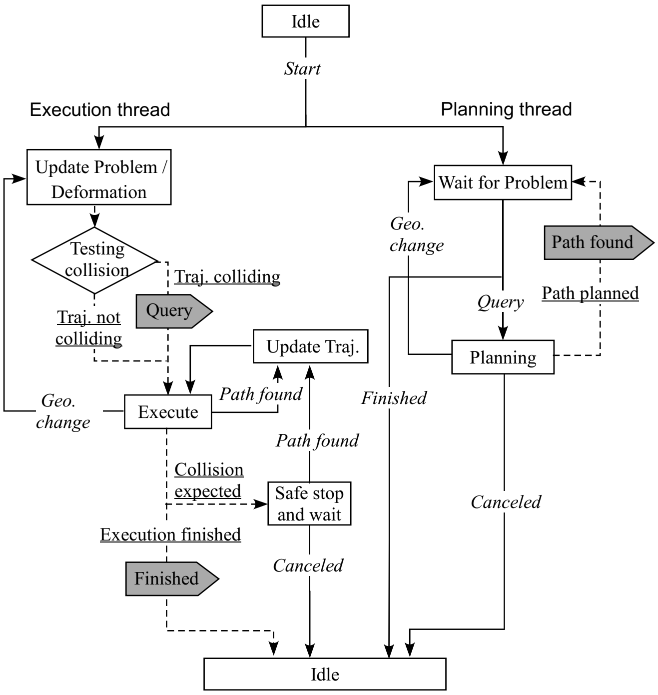

Fig. 2. Replanning scheme with parallel planning and execution

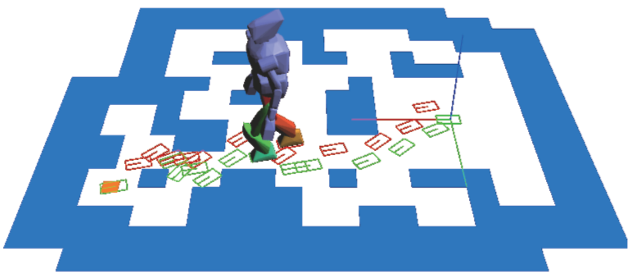

Fig. 3. 2D environment including prohibited areas.

B. Footstep planning

Based on this dynamic walking pattern generation, planning is performed by taking advantage of the half-step sequence that can be easily "cut" at the static connecting configuration to replace the following half-steps. The planner continuously reads the coordinates of the goal and obstacles, and checks if there is a new target or new collisions. The newly generated half-step sequence is connected to the previously generated one using path connection.

As half-steps have the good property of low-dimensionality (only 3 parameters), it is possible to obtain a quite dense coverage by the set of feasible half-steps generated by offline dynamic simulations. Although we use a finite set of half-steps (about 200) for real-time planning, it gives us a very good expressiveness of 3D walking trajectory compared with other methods where only 15 to 30 steps are considered [5], [6].

During the planning phase, we use a discretized version of RRT in [1] to search for a collision-free sequence of half-steps. This method is *ad hoc* and not yet completely satisfying as RRT is not very well suited for discrete footstep planning, but since we have about 200 half-steps, this approach is overall better than an A* search whose performance quickly decreases when the number of possible actions increases.

IV. Experiments

All the experiments were performed on the robot HRP-2. We used a flat surface of 4m by 6m, and obstacles such as a table and a chair.

An object is selected as the 2D goal in the motion capture area (see Fig. 1). The robot is required to reach the goal object by putting one of his feet within the range of 15cm. The environment can also have 2D forbidden zones as shown in Fig. 3. The forbidden zones are depicted by colored surfaces. The obstacles and the robot are tracked by the motion capture system, sending 3D positions over the local network.

We tested different scenarios where we modified online the obstacles and goal positions. There are failure cases, but most of the time the planner is able to successfully return new sequences of steps to avoid unpredicted collisions caused the environmental changes. The planner takes about one second to find a path of 4m long with 30 steps, taking into account two obstacles defined with about 60 thousands of triangles in total. For shorter paths (less than one meter long), the planner can quickly plan tens of paths in a second. This helps the robot improve portions of the current path when the obstacles and the goal do not move.

However, as the planner does not always have enough time to produce close-to-optimal paths, and the robot occasionally follows unnecessarily long paths. In future work we aim at reducing planning time through the use of advanced computation techniques such as parallelization. We will also integrate the robot localization and plan accordingly to allow online correction of its position.

Acknowledgment

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