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Dynamic Envelopes and Robustly, Continuously Collision-free Trajectories

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ABSTRACT

In an unpredictable real-world environment, how the objects move is usually not known beforehand. Thus, whether a robot trajectory is safely collision-free or not has to be tested on-line based on sensing as the robot moves in the environment and taking into account robot motion uncertainty. The problem is more challenging if the robot has a high degree of freedom, such as a mobile manipulator. In this talk, we introduce a general on-line approach to test if a given trajectory segment of the robot, which can have high-DOF, is continuously collision-free, and moreover, if the trajectory segment is *robustly* collision-free, that is, if some deviation of the trajectory within certain "tunnel" of the configuration-time space of the robot is also continuously collision-free. Our method is based on the novel concept of dynamic envelopes [1], which takes advantage of progressive sensing over time without predicting motions of obstacles or assuming specific obstacle motion patterns.

Assume that every obstacle in the unpredictable environment can have a linear speed no greater than v_{max}. Let $R(C)$ be the physical region occupied by the robot at configuration C. To test if the robot at configuration C and future time t is collision-free or not, i.e., if the configuration-time point $x = (C, t)$ is collision-free or not, we define a *dynamic envelope* $E(x, \tau)$ as the closed surface surrounding $R(C)$, such that the minimum distance between $R(C)$ and $E(x, \tau)$ is $v_{max}(t-\tau)$, for sensing time $\tau < t$. If $E(x, \tau)$ is free of obstacle, $x= (C, t)$ is detected collision-free for sure at sensing time τ. As $E(x, \tau)$ is a function of τ, this concept facilitates progressive sensing over a period time to detect if (C, t) is surely collision-free or not *before* time t. Moreover, if the configuration-time point (C, t) is detected collision-free, we will show that a neighborhood of (C, t) is also collision-free. Based on that, we will further introduce an on-line approach to test if a continuous "tunnel" of trajectories in the robot's configuration-time space is collision-free or not by checking if a set of discrete configuration-time points are collision-free or not [2]. Thus, through the concept of dynamic envelopes, we can achieve on-line testing of whether a trajectory segment is continuously and robustly collision-free or not. This approach can be used by a real-time motion planner, such as the RAMP [3], to plan continuously and robustly collision-free trajectories in unpredictable environment.

If a robot has multiple rigid links, a dynamic envelope can be viewed as the union of dynamic envelopes for individual links, which are usually of simple shapes. Therefore, the detection of whether a dynamic envelope intersects an obstacle can be performed quite efficiently via existing fast collision detection algorithms. However, if a robot consists of deformable links, such as a

continuum manipulator, existing intersection detection algorithms based on mesh models of rigid objects are less suitable. We have developed an efficient intersection detection algorithm between an n-section continuum manipulator, with deformable sections, and mesh models of obstacles [4]. The algorithm directly applies to on-line intersection checking between a dynamic envelope of a continuum manipulator and obstacles. The intersection checking for each robot configuration takes only a few percent of the time required by an existing mesh-based collision detection algorithm.

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