A Landmark-based Motion Planner for Rough Terrain Navigation

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Abstract: In this paper we describe a motion planner for a mobile robot on a natural terrain. This planner takes into account placement constraints of the robot on the terrain and landmark visibility. It is based on a two-step approach: during the first step, a global graph of subgoals is generated in order to guide the robot through the landmark visibility regions; the second step consists in planning local trajectories between the subgoals, satisfying the robot placement constraints.

1. Introduction

Autonomous navigation on natural terrains is a complex and challenging problem with potential applications ranging from intervention robots in hazardous environments to planetary exploration. Mobility in outdoors environments has been demonstrated in several systems [16, 7, 8, 3].

The adaptive navigation approach currently developed at LAAS within the framework of the EDEN experiment [3] demonstrates fully autonomous navigation in a natural environment, gradually discovered by the robot. The approach combines various navigation modes (reflex, 2d and 3d) in order to adapt the robot behaviour to the complexity of the environment. The selection of the adequate mode is performed by a specific planning level, the navigation planner [11] which reasons on a global qualitative representation of the terrain built from the data acquired by the robot’s sensors.

In this paper, we concentrate on the motion planning algorithms required for the 3D navigation mode [13], selected by the navigation planner when very rugged terrain has to be crossed by the robot. On uneven or highly cluttered areas, the obstacle notion is closely linked with the constraints on the robot attitude, and therefore constrains the robot heading position. Planning a trajectory on such areas requires a detailed modeling of the terrain and also of the robot’s locomotion system.

Several contributions recently addressed motion planning for a vehicle moving on a terrain [15, 9, 4, 2, 6]. In particular, the geometric planner we proposed in [15, 6] is based on a discrete search technique operating in the \((x, y, \theta)\) configuration space of the robot, and on the evaluation of elementary
feasible paths between two configurations. The overall efficiency of the approach was made possible by the use of fast algorithms for placing the robot onto the terrain (Figure 1) and checking the validity of such placements.

In the navigation experiments previously conducted with a real robot [13], motion control was limited to executing the paths returned by this planner by relying on odometry and inertial data. The unpredictable and cumulative errors generated by these sensors, especially significant on uneven and slippery areas, often caused important deviations leading to a lack of robustness at execution. To overcome this problem, the robot has to be equipped with environment sensors (eg. cameras) that can provide additional information by identifying appropriate features of the terrain, and allow to use sensor-based motion commands. Such primitives are more tolerant to errors than classical position-controlled primitives, but their feasibility has to be checked in term of visibility of the landmarks along the trajectory.

The contribution of this paper is to propose a motion planning approach which considers a set of given landmarks (eg. terrain peaks [5]) in the terrain model, and computes a partitioning of the terrain into regions where particular landmarks are visible. The approach allows to produce trajectories that remain, whenever possible, inside these visibility regions where the robot can navigate with respect to the given landmarks using closed-loop primitives relying onto the sensor’s data.

2. The Motion Planning Approach
2.1. Problem statement

We consider a geometric model of an articulated robot illustrated by Figure 1. The robot is composed of several axles linked by passive joints allowing to adapt its shape to the terrain relief. The terrain is described by surface patches defined from an elevation map in z associated with a regular grid in (x, y). The terrain model also contains a set of point landmarks corresponding to major terrain features that the robot should be able to track at execution. The robot motions are constrained by: