Climbing Steep Inclines with a Six-Legged Robot using Locomotion Planning

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Abstract—We present an approach to climb crater walls using the six-legged robot CREX (CRater EXplorer).

The control architecture consists of a motion execution engine, a mapper, and a locomotion planner which maintains stability when climbing the crater wall.

I. INTRODUCTION

Legged robots have several advantages in comparison to wheeled robots when climbing unstructured terrain. One of them is that they are able to freely place their feet in order to maximize stability and minimize slip. Here we present our approach to exploit these advantages by combining a local mapper with a locomotion planner.

II. LOCAL MAPPING

We model the local 3D environment of the robot using a truncated signed distance function (TSDF). Each distance measurement sensed by the LiDAR is ray-traced through a voxel grid. In each cell the signed distance to the surface and measurement uncertainty is updated using the Kalman update rule. To compute the optimal foot placement on the surface a mesh is reconstructed on the basis of the voxel grid using the Marching Cubes algorithm [1] also considering the uncertainties of the integrated measurements. Since this approach models free space, while the actual surface information is reconstructed, it is more robust against outliers, dynamic changes in the environment and the error in the odometry of the robot.

III. LOCOMOTION PLANNER

The locomotion planner is designed, to move the robot by a given motion command, while keeping static stability. This is achieved by using a simple motion pattern in combination with a planning approach. The motion pattern consists of five phases:

- 1) movement of the body
- 2) tilt/pan for liftoff
- 3) relaxation of the liftoff spring
- 4) single leg movement
- 5) tilt/pan for body movement

To minimize slip during the movement phase, the robot utilizes a force balancing approach, to achieve ground contact with all feet.

After every motion phase, an A-Star planner is used to preplan a series of steps that maintain static stability. The



Fig. 1. Left: CREX is a six-legged robot with 24 degrees of freedom (four revolute joints per leg). It has rubber feet attached to a spring-suspended lower leg. The length of the lower leg is measured by a linear encoder, so the kinematics can be calculated accurately. Forces and torques in 6 DOF are measured at the body mount of each leg. It utilizes a *Velodyne HDL-32E* LiDAR for localization and local mapping.

Right: CREX inside local map. Height is encoded by different colors (one cycle per meter). White dots mark candidate foot positions.

termination criteria for the A-Star planner is that every foot is moved at least once. During the planning phase the local map is used, to sample touchdown positions on the surface of the map. The next lift-off pose and touchdown position are then determined from the result of the planning and given to the motion execution. To avoid ground collisions during leg movement, a collision-free trajectory above the map is computed.

IV. PRELIMINARY RESULTS

Using this approach, the CREX Robot was repeatedly able to climb up a distance of 6 meters on a moon-like crater with an inclination of 35°. The artificial crater is a solid mockup of a lunar crater explicitly created for such experiments (Fig. 1).

ACKNOWLEDGEMENT

This approach was developed within the project Entern [2] which targets autonomous crater and cave exploration.

This work is funded by the Space Agency of the German Aerospace Center (DLR) with federal funds of the Federal Ministry of Economics and Technology (BMWi) in accordance with the parliamentary resolution of the German Parliament, grant no. DFKI 50RA1406 (DFKI) and 50RA1407 (University of Bremen).

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