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Demonstration of Quadrupedal Locomotion over Rough Terrain using the LittleDog Robot

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This video presents work by researchers at The Florida Institute for Human and Machine Cognition (IHMC) on the DARPA funded Learning Locomotion program. This program started in 2005 and finished in 2009.

The goal of the Learning Locomotion program was to develop control algorithms for autonomous traversal of large, irregular obstacles by an unmanned quadrupedal robot. The program was designed to allow multiple teams to compete for the fastest speeds across the terrain boards using identical hardware.

Terrain sensing and localization issues were eliminated by providing a high resolution height map of the terrain as well as real time pose information of the robot on the terrain. The objective for each trial was to reach the goal position as fast as possible.

Over the course of the program there were numerous terrain boards that the robot had to cross. These terrain boards were designed to simulate what an unmanned ground vehicle would face in the real world, and included steps, barriers, rocks, logs, and slopes.

Our algorithm consists of three major components. The first is terrain scoring. The terrain file is gridded and then each point is assigned a score based on the local geometry of the terrain. We then coagulate the good points to reduce the number of points for the planner to consider.

The second major component is the footstep planner. For each trial, we have 90 seconds to plan our route over the given terrain. Our footstep planner is depth first and is seeded with initial step conditions and a body path estimate.

The body path estimate is generated based on the terrain features and quality of step locations.

We generate multiple plans for each trial and evaluate each plan using a non-dynamic simulator and the fastest estimated plan is selected. On average, our planner takes about 5 seconds to plan a route from start to goal. It then takes approximately another 4 seconds to perform the non-dynamic simulation for each plan. For each trial, we generally had between three and eight plans to choose from.

During the trial, a body path is calculated for each step to keep the foot placements in the planned footsteps. The body path is determined to minimize excess body movement (i.e. back and side to side), to optimize stability, and to guarantee that all joints operate in their kinematic range. Real-time adjustments are made based on the feedback from the foot force sensors and the actual body pose.

One of our major developments in this program is the Xgait. In a regular crawl gait, only one leg swings a time, and the ordering of the swing leg is left hind, left front, right hind, and then right front. For a static crawl the center of mass never leaves the polygon of support. The Xgait is a method of parameterizing a crawl gait to easily transition from a static crawl gait to a trot.

A common way to parameterize crawl gaits is with the duty factor, β [10]. This parameter has been used by Hirose [11] to develop the dynamic and static fusion gait. Although this approach by Hirose does allow for smooth transitions between crawl, dynamic crawl, and trot gaits, it has some limitations. The duty factor parameter only makes sense when describing an entire gait cycle, all four legs have a transfer or swing phase, and the duration of the transfer phase for each of the legs is equal. Another limitation is that the duty factor does not have a direct physical meaning with regard to the stability of the gait.

The Xgait is based on the regular gait leg sequencing (hind, front, opposite hind, opposite front). It controls the timing of the leg swings and body shifts using two parameters. Each Xgait step (see Figure 1) consists of a front leg swing, the opposite diagonal leg swing, and a corresponding body shift.

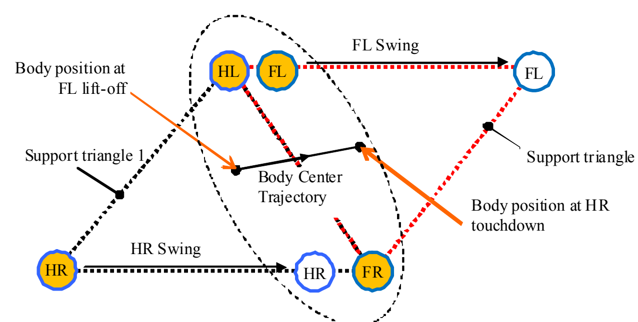

Figure 1: This figure shows the footsteps and body center shift for an Xgait step. In this step, the front left (FL) leg swings forward, the hind right (HR) leg swings forward, and the body shifts forward. Note that body center position starts inside Support triangle 1. Also note that at the end of the Xgait step, the body center is in Support triangle 2.

The Xgait step is parameterized by two parameters; X_{FTD} (Front Touchdown) and X_{HLO} (Hind Liftoff) (see Figure 2). X_{FTD} is the signed perpendicular distance of the body center position to the trot line at the time the front leg touches down and ends it swing. From a stability point of view, if the body center position when the front leg touches down is *less* than X_{FTD}, then the step is more stable. Therefore, X_{FTD} is defined as a maximum, not to be exceeded, value.

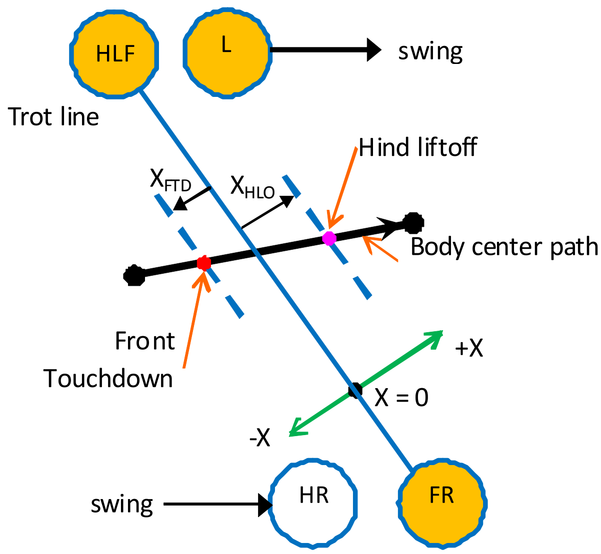

Figure 2: This figure shows the parameterization for and Xgait step involving the front left and hind right swings. The figure is a detailed view from Figure 1. The view is from above with the foot positions projected onto a plane normal to gravity. The trot line is the line connecting the two support feet that do not swing during the Xgait step. The Xgait step is parameterized by the X_{FTD} and X_{HLO}. These are signed perpendicular distances to the trot line, with positive being in the direction of body center travel.

X_{HLO} is the signed perpendicular distance of the body center position to the trot line at the time the hind leg lifts off the ground and starts swing. From a stability point of view, if the body center position when the hind leg lifts off is *greater* than X_{HLO}, then the step is more stable. Therefore, X_{HLO} is defined as a minimum value.

The Xgait enables, with the adjustment of X_{FTD} and X_{HLO}, the ability to continuously adjust the gait between a crawl and a trot. On rough terrain, these parameters were set such that the robot walked with a static crawl gait. On smooth terrain, the Xgait parameters were set such that the robot walked with a dynamic gait close to a trot.

In order to cross some of the more challenging terrain, dynamic jumping maneuvers were developed. These maneuvers can be seen on boards like the steps and barrier. Other boards required terrain conforming swing trajectories, careful placement of the foot, and reduced body speed.

Overall, our approach was highly successful. We consistently performed well during the program. The final test consisted of ten different terrain configurations, with six of them unknown boards. We crossed 28 out of 30 trials, achieving at least two successful runs out of three trials on every board. The metric speed for the program was 7.2 cm/s and we crossed eight out of ten boards at greater than metric speed with an overall average speed of 11.2 cm/s.

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