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Semi-autonomous Concurrent Driving-Stepping Locomotion

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Locomotion in uneven terrain is important for a wide range of robotic applications, including Search&Rescue operations. Our robot Momaro, which was developed for participation in the DARPA Robotics Challenge [1], features a unique locomotion design consisting of four legs ending in pairs of steerable wheels (see Figs. 1 and 2). This allows the robot to omnidirectionally drive on suitable terrain, while also stepping over obstacles too high to drive over. The legs have three pitch joints in hip, knee and ankle. Furthermore, the ankle can rotate around the yaw axis and the two wheels can be driven independently. All joints are Robotis Dynamixel Pro actuators. The leg segments are carbon fiber springs, thus providing passive adaptation to terrain.

Due to the typically limited communication bandwidth, a suitable balance between autonomous actions conducted by the robot and teleoperation commands has to be found to allow robot operations to finish within acceptable time. Our system addresses this concern by autonomously executing weight shifting and stepping actions. The main environmental representation used is a 2D heightmap (see Fig. 2) created by aggregating the measurements of a 3D laser scanner, maintaining an egocentric multiresolutional surfel map [2] and extracting the height information. In this representation, the system detects obstacles close to the robot wheels and automatically constrains foot motions to avoid contact.

While the operator always retains control of the velocity of the robot base using a joystick, steps can be triggered either automatically or manually. The automatic mode always decides on the wheel pair which most urgently needs stepping for continued base movement with the requested velocity.

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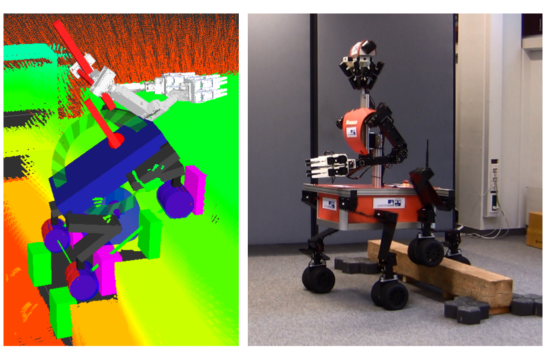

Fig. 1. **Left**: Momaro climbing stairs in simulation. The green and purple boxes indicate detected obstacles which constrain the wheel motion. **Right**: Momaro stepping over a wooden bar obstacle.

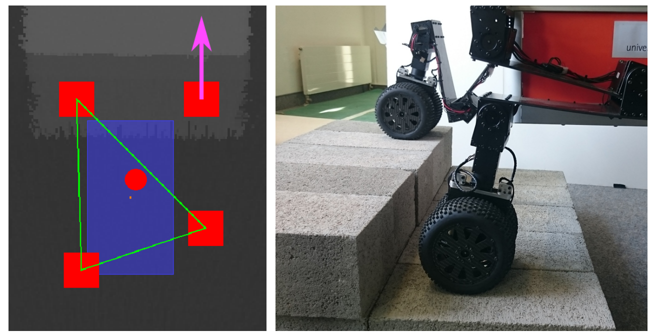

Fig. 2. **Left**: 2D heightmap of Momaro standing on the first of two steps. The robot is in stable configuration to lift the right front leg. Red rectangles: Wheel positions, red circle: COM, blue: robot base, green: support polygon. **Right**: The right front leg is lifted and placed on the next step.

To be able to lift a wheel, the robot weight must be shifted away from it. Ideally, the 2D projection of the center of mass (COM) of the robot should lie in the center of the triangle formed by the other three wheel pairs. This ensures static balance of the robot while stepping. The system has three ways of achieving this goal: i) moving the base relative to the wheels in sagittal direction, ii) driving the wheels on the ground relative to the base, and iii) modifying the leg lengths (and thus the base orientation). All three methods have been used in the situation depicted in Fig. 2.

The balance control behavior ensures static balance using foot motions on the ground (constrained by the detected obstacles) and leg lengths. If it is not possible to move the COM to a stable position, the system waits for the operator to adjust the base position or orientation to resolve the situation.

The stepping motion itself is a parametrized motion primitive in Cartesian space. As soon as the wheel is in the target position, the weight is shifted back using balance control. The operator is then free to continue with either base velocity commands or further steps.

The described system has been developed in simulation (see Fig. 1) and has successfully and reliably overcome obstacles of various shapes, including stairs of up to 40° incline. The system is now undergoing testing on the real robot. Initial results (see Fig. 2) indicate that it is able to perform comparably to simulation results, demonstrating the feasibility of concurrent driving-stepping locomotion.

REFERENCES

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