NAO Walking Down a Ramp Autonomously

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***Abstract*— In this work, we present methods that enable a humanoid robot to traverse ramps using only vision and inertial data for sensing. Our video illustrates the method and shows the results obtained with a Nao humanoid. Using the proposed approach, the robot is able to autonomously walk down a 2.10 m long ramp at an inclination of 20°.**

I. INTRODUCTION

To fulfill high-level tasks, humanoid service robots must be able to autonomously and robustly navigate in man-made environments. These environments can be arbitrarily complex, containing multiple levels and various types of stairs or ramps connecting them. We previously presented techniques for autonomously climbing spiral staircases with humanoid robots [1]. In this work, we extend this research direction by walking down ramps.

On a Nao humanoid, we apply kinesthetic teaching to learn single stepping motions for the ramp. As we show in the experiments, by using the learned motions and integrating monocular vision and inertial data, the Nao is able to autonomously walk down a 2.10 m long ramp at an inclination of 20°. Fig. 1 (left) shows the humanoid robot in front of the ramp. The accompanying video shows the complete process of locating the beginning of the ramp using visual observations, walking down with regular corrections based on the inertial data, and finally determining the end of the ramp by detecting the ending edge before exiting the ramp.

II. HUMANOID ROBOT PLATFORM

In our work we use a V4 Nao humanoid by Aldebaran Robotics. The robot has 25 degrees of freedom, is 58 cm tall and weighs about 5 kg. To measure the angle of each joint, Nao is equipped with Hall effect sensors. For sensing the environment, we make use of the lower monocular camera located in the head, which has a 72.6° diagonal field of view and is able to observe the area in front of the robot's feet. The inertial measurement unit (IMU) yields an estimate about Nao's orientation as roll and pitch angles. Since the Nao's hard plastic feet would slide on the inclination of our ramp, we slightly increased the feet's friction by attaching thin plastic sheets. While this prevents the robot from sliding, it does not create too much friction, which would impede the regular walking behavior.

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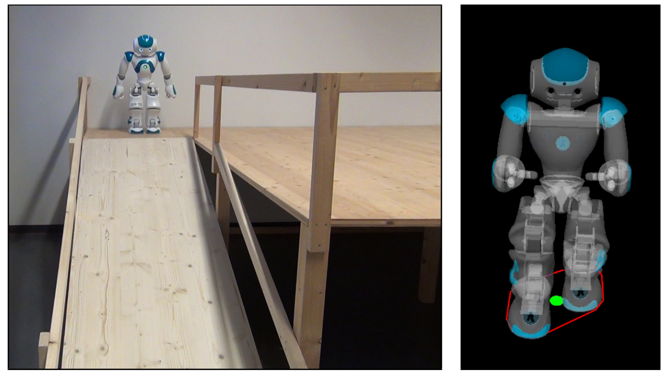

Fig. 1. *Left:* The Nao humanoid in a two-level environment, connected by a ramp. *Right:* Support polygon (red) and projected center of mass (green dot) for a double-support phase on the ramp.

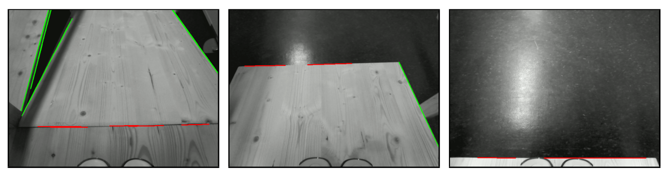

Fig. 2. By extracting lines from the camera images, the robot can detect the start (left) and end of the ramp (center and right image). The detected horizontal lines are marked in red.

III. LEARNING BASIC MOTIONS

We apply kinesthetic teaching [1] to learn single stepping motions. To this end, we turn the robot's motors off and manually move it to statically stable poses during a single stepping motion. The Hall effect sensors yield information about all joint angles at these poses. We record the corresponding keyframes and interpolate between them with Bézier curves to create smooth movements. We optimize the motions for static stability on the ramp, which is achieved by moving the robot's projected center of mass as close to the center of the support polygon as possible (see Fig. 1, right). While whole-body motion planning [2] can also produce stable motions, planning long trajectories for systems with many degrees of freedom is not yet feasible for realtime navigation.

With our method, we learn basic steps to enter and exit the ramp, walking steps on the ramp, and small correction steps to account for drift and to correct the robot's orientation on the ramp. To safely enter and exit the ramp, the robot needs to execute relatively large steps. This requires a low center of mass. To reduce the strain on the servos, the robot alternates the stance and swing leg by mirroring the recorded stepping motions.

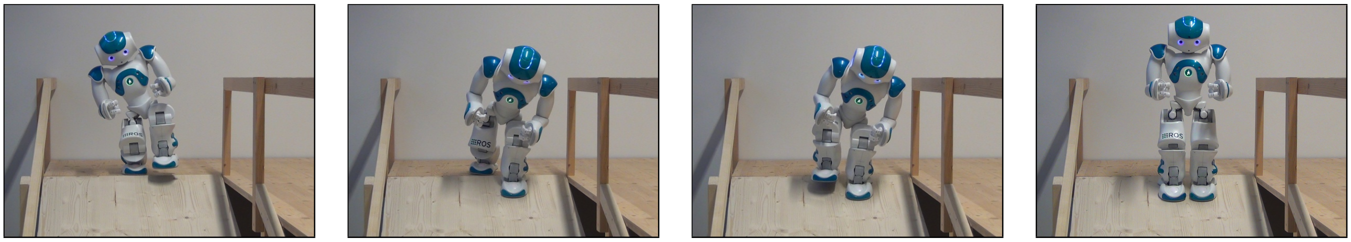

Fig. 3. Nao executes a single step onto the ramp after detecting the start in its camera image.

IV. LOCALIZATION AND NAVIGATION

Due to foot slippage, inaccurate hardware calibration, and joint backlash, the robot's motion is affected by noise and drifts over time. It is not possible to walk down the ramp with an open-loop behavior, but the robot has to correct its heading regularly. Additionally, it is necessary to accurately detect the beginning and the end of the ramp to carefully enter and exit it without falling.

A. *Recognizing Boundaries of the Ramp*

To detect the top and bottom edges of the ramp, Nao enters an upright standing pose and obtains a grayscale image from its lower camera (see Fig. 2). A combination of the Canny edge detection algorithm and the probabilistic Hough transform [3] yields a number of straight lines in the image. In our case, we are only interested in approximately horizontal lines and extract the one closest to the feet. From this, we can estimate the actual distance and orientation to the edge similar to [1]. To reach the entry point of the ramp, we apply the Nao's standard walking engine in the horizontal 2D plane [4].

To exit the ramp at the bottom, different stepping motions on the ramp are used depending on the distance to the edge. The robot chooses a double step, a single step, or a small step repeatedly until the bottom edge is reached. Finally, when it is aligned accurately with the bottom edge, the robot can execute the exiting walking motion and continue walking on the ground plane with the 2D walking engine.

B. *Correction of Heading*

Due to drift, the robot loses its original heading after a few steps. This could lead to a collision with the handrail or even a fall since any change in the yaw results in changes of the projected center of mass due to the ramp inclination. Thus, we make use of the Nao's internal IMU to obtain the current roll angle. From this we can infer the orientation on the ramp and correct the heading with small steps.

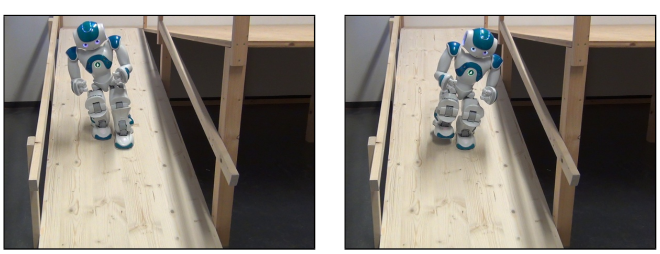

Fig. 4. Nao executes statically stable steps on the ramp and regularly corrects its heading based on IMU data.

V. RESULTS & DISCUSSION

Our proposed method enables the Nao humanoid to walk down ramps autonomously using only its onboard monocular camera and IMU as sensory input. Fig. 3 shows a sequence of the first step the robot executes to get onto the ramp and Fig. 4 illustrates an intermediate step on the ramp. Our approach works successfully in practice and allows the robot to reliably find the entry and exit points of the ramp and correct for drift while walking on the ramp. Note that the presented method can be applied for walking up ramps as well. In general, our approach of using monocular vision and IMU data to determine appropriate motions to walk ramps can be applied to any humanoid robot.

During our experiments, we found the main challenge to be the first step onto the ramp. Even small errors in the initial orientation can lead to a fall. Lateral drifts to the side may also be a failure case. They are uncommon, but can add up over the whole length of the ramp. In the future, we will use visual cues to detect the side boundaries of the ramp to help localizing in these cases.

We also plan to increase the robustness by incorporating range measurements, e.g., laser data in addition to visual observations in a global localization algorithm [5] and using footstep planning [6] instead of learned stepping behaviors. This would additionally require whole-body planning or a walking controller designed for uneven terrain to execute the planned footsteps.

If the inclination of the ramp is not known in advance, it can be estimated on-line by carefully placing the foot onto the ramp with compliant ankle joints and afterwards applying our approach to step down the ramp.

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