Chapter 2
Enhanced Footsteps Generation Method for Walking Robots Based on Convolutional Neural Networks

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ABSTRACT

In this chapter, the problem of finding a suitable foothold for a bipedal walking robot is studied. There are a number of gait generation algorithms that rely on having a set of obstacle-free regions where the robot can step to and there are a number of algorithms for generating these regions. This study breaches the gap between these algorithms, providing a way to quickly check if a given obstacle free region is accessible for foot placement. The proposed approach is based on the use of a classifier, constructed as a convolutional neural network. The study discusses the training dataset generation, including datasets with uncertainty related to the shapes of the obstacle-free regions. Training results for a number of different datasets and different hyperparameter choices are presented and showed robustness of the proposed network design both to different hyperparameter choices as well as to the changes in the training dataset.

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INTRODUCTION

Gait generation is one of the central problems in walking robotics, as it encapsulates a number of challenges associated with this type of robots. Unlike the robots with wheels or tracks, the motion of walking robots of all types is characterized by acquiring and breaking contacts with the supporting surface, which makes the motion planning fundamentally difficult. As discussed in (Bouyarmane et al., 2017), the task of planning the motion trajectory that includes periodic contacts requires placing the contact points at a zero-measure subset of the configuration space of the robot. The difficulty of this problem is increased further by the requirements associated with the robot's dynamics, limiting possible motions and placing restrictions associated with vertical balance of the robot (Vukobratovic & Borovac, 2004), the limitations associated with friction cones, finite torques available for the robot motors and others (Kuindersma et al., 2016).

As a result, many of the successful approaches to motion planning for walking robots rely on decomposition of the original problem into a number of more tractable sub-problems. A particularly popular approach is to first plan the sequence of steps for the robot (Kanoulas et al., 2018), then plan the trajectories for some of its key points, usually its feet and its center of mass (Kajita et al., 2001, 2002), then solve the inverse kinematics problem (Suleiman et al., 2018) and finally use its solution as a control input to the feedback controller that is designed to stabilize the obtained trajectory of the robot (Galloway et al., 2015). Some of these sub-problems had been solved by designing highly efficient algorithms. For example, paper (Kuindersma et al., 2014) suggested reformulation of the stable trajectory generation problem for the center of mass of the robot as a linear quadratic regulator (LQR) problem, which allows solving it using the robot's on-board computers. In (Panovko et al., 2016; Jatsun et al., 2016b) the center of mass trajectory for a bipedal exoskeleton was obtained by directly solving the dynamic ZMP equation. The trajectory generation problem can be more challenging when there are additional contacts between the robot and the environment. In (Jatsun et al., 2017a) the problem of standing up from a chair is considered. This requires breaking the contact between the chair and the robot while retaining the contact between the robot and the supporting surface. In the paper, the problem of trajectory generation was decomposed into states, allowing treating the two different contact scenarios separately.

However, the problem of planning footstep sequences for bipedal walking robots has not yet been solved completely. It can be said that the challenges of the original task of motion planning for the walking robots had been embedded into this sub-problem. In particular, planning footstep sequences requires finding feasible paths over terrain with obstacles, such that the free space is non-convex. This type of motion planning problems can be solved via methods such as rapidly exploring random trees (RRT) or probabilistic roadmaps (PRM), which rely on random sampling to generate a feasible path (LaValle, 1998; LaValle & Kuffner, 2000). Alternative approaches are based on decomposition of the free space into convex obstacle-free regions, and then using mixed integer convex programming to find the optimal step sequence. The disadvantage of the later approach is that it requires the use of additional decomposition algorithm to create a set of the convex obstacle-free regions. There are a number of algorithms proposed, including IRIS based on semidefinite programming (Deits & Tedrake, 2015) and a stereographic projection-based method (Savin, 2017).

The use of mixed integer convex programming methods for motion planning is associated with a significant computational cost. The computational complexity of the problem rises with the number of obstacle-free regions. This motivates filtering out the regions that cannot be used as footholds (due to their size or shape) before initiating the optimization procedure. This is a classification problem which