Chapter 1
Motion Planning Method for In-Pipe Walking Robots Using Height Maps and CNN-Based Pipe Branches Detector

Sergei Savin
https://orcid.org/0000-0001-7954-3144
Innopolis University, Russia

ABSTRACT

In this chapter, the problem of motion planning for an in-pipe walking robot is studied. One of the key parts of motion planning for a walking robot is a step sequence generation. In the case of in-pipe walking robots it requires choosing a series of feasible contact locations for each of the robot's legs, avoiding regions on the inner surface of the pipe where the robot cannot step to, such as pipe branches. The chapter provides an approach to localization of pipe branches, based on deep convolutional neural networks. This allows including the information about the branches into the so-called height map of the pipeline and plan the step sequences accordingly. The chapter shows that it is possible to achieve prediction accuracy better than 0.5 mm for a network trained on a simulation-based dataset.

INTRODUCTION

Pipelines are an important part of modern engineering and transportation infrastructure. Replacing aging pipelines is costly, which motivates performing periodic inspections and repairs in order to prolong the use of the existing ones (Ilg

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et al., 1997). However, this activity is labor-intensive and is not always possible without the use of in-pipe robots (Tătar et al., 2007; Chatzigeorgiou et al., 2011).

In-pipe robots allow performing inspections of the inner surface of the pipe, which comes in direct contact with the transported material. In-pipe robots can be viewed as transportation systems carrying a suit of sensors or a specialized equipment designed for the inspection or repair tasks. The task of the in-pipe robots is then to move from point to point or along a given trajectory inside the pipe. This includes moving through pipes with changing diameter, pipes with horizontal and vertical sections, pipes with branches, T-junctions and L-turns (Roslin et al., 2012). The complex geometry of the inner surface of pipelines makes the problem of motion planning more difficult for in-pipe robots, compared with robots and vehicles moving on the ground.

One of the standard approaches to designing in-pipe robots is to use structures that make the problem of contact interaction with the inner surface of the pipe simpler. Examples of such designs include robots with passive or active parallel structures that press the robot's wheels or tracks against the inner surface of the pipe (Roh & Choi, 2005, Ryew et al., 2000; Jun et al., 2004). There are also examples of robots using loaded springs to directly push the robot's wheels against the inner surface of the pipe (Chatzigeorgiou et al., 2015; Horodinca et al., 2002). Some of the robots of this type have demonstrated the ability to move through pipelines with bends, and with horizontal and vertical sections (Tătar et al., 2007). The robot shown in (Nishimura et al., 2012) demonstrated the capability to move through T-junctions. These types of designs might also require the use of an additional steering mechanism (Choi & Roh, 2007). Advantages of these designs include reliable contact with the inner surface of the pipe, relatively simple control and relatively few motors required. The disadvantages of these designs include relatively small range of pipe diameters that a particular robot can navigate, limited possibilities in traversing sharp bends and turns, difficulties in moving through pipes with non-circular diameters, or equivalently, pipes contaminated with material deposits on their inner surface (Singh et al., 2017). There are also examples of in-pipe robots with wheels and tracks that do not use additional mechanical structures to improve the contact with the inner surface of the pipe (Ong, 2003). These types of robots are not capable of moving in vertical sections of pipelines.

One of the ways to improve the capabilities of in-pipe robots is to use designs that facilitate agile locomotion. One of such designs is in-pipe walking robots (Gálvez et al., 2001; Pfeiffer, 2007; Silva & Tenreiro, 2007). Examples of such robots can be found in (Zagler & Pfeiffer, 2003; Roßmann & Pfeiffer, 1996, 1998), where an eight-legged prototype was shown, in (Savin et al., 2017a) where a six-legged robot moving in spatially curved pipes was discussed, and in (Savin & Vorochaeva, 2017b, 2017c) where a four-legged robot designed for planar pipelines was considered.

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