Chapter 9
Design and Implementation of a Step-Traversing Two-Wheeled Robot

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ABSTRACT

In this chapter, the authors present the design and implementation of a step-traversing two-wheeled robot. Their proposed approach aims to extend the traversable workspace of a conventional two-wheeled robot. The nature of the balance problem changes as the robot is in different phases of motion. Maintaining balance with a falling two-wheeled robot is a different problem than balancing on flat ground. Active control of the drive wheels during flight is used to alter the flight of the robot to ensure a safe landing. State dependent feedback controllers are used to control the dynamics of the robot on ground and in air. Relationships between forward velocity, height of step, and landing angle are investigated. A physical prototype has been constructed and used to verify the viability of the authors' control scheme. This chapter discusses the design attributes and hardware specifications of the developed prototype. The effectiveness of the proposed control scheme has been confirmed through experiments on single- and continuous-stepped terrains.

1. INTRODUCTION

Mobile intelligent robots are expected to play an increasing role in aiding humans in various tasks. Advancements in robotic technologies have enabled increasing number of robots to be deployed in the fields of exploration, surveillance, health care, and entertainment. Robots that need to operate in an uncontrolled human environment will have to be able to navigate stepped and uneven terrain. Properly implemented control methods will ensure the usability and safe deployment of these robots. Many existing stair climber robots have used rocker-bogie mechanisms or crawler mechanisms (Volpe, Balaram, Ohm, &

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Ivlev, 1996; Hayati et al., 1997; Saranli, Buehler, & Koditschek, 2001; Lamon, Krebs, Lauria, Siegwart, & Shooter, 2004; Guarnieri, Takao, Fukushima, & Hirose, 2007). Robots using these mechanisms rely on the static stability of the platform to perform step traversal. Relying on static stability has drawbacks of low traversal speed and increased complexity in the structure design. Any external perturbation which forces these robots outside their basin of stability will lead to loss of control and inability to recover.

Dynamically stable robots offer better agility and are more robust to external disturbances (Lauwers, Kantor, & Hollis, 2006; Kumagai & Ochiai, 2008; Xu & Au, 2004; Brown & Xu, 1997). Such advantages can be used to achieve rapid, stable transition through stepped terrain (Kikuchi et al., 2008). In our research, we focus specifically on using a two-wheeled robot to travel continuously through stepped terrain without losing balance. The problem of maintaining balance with a falling two-wheeled robot is highly non-linear. The nature of the balance problem changes as the robot is in different phases of motion. A free falling robot is a different control problem than a robot climbing a step or traversing flat ground.

Two-wheeled robots have been a popular research platform due to their simple design yet complex dynamic behavior. Most of the research literature available focuses on continuous ground balance (Teeyapan, Wang, Kunz, & Stilman, 2010; Stilman, Olson, & Gloss, 2010; Grasser, D'Arrigo, Colombi, & Rufer, 2002). The problem of balancing a two-wheeled robot through discontinuous terrain has received relatively little attention. Related research includes a reconfigurable hopping rover as proposed in Schmidt-Wetekam et al. (2007) and Schmidt-Wetekam et al. (2011). The hopping rover resembles a 3 dimensional reaction wheel pendulum with a set of orthogonally arranged drive wheels. The drive wheels are used to provide torque for attitude correction to re-orient the vehicle during flight and ground balance. The hopping action is provided by an extendable leg. The hopping robot exhibited good dynamic stability on a flat surface, but performance on a stepped surface was not evaluated.

In this chapter, we introduce the development of a step traversing two-wheeled pendulum robot (Yap & Hashimoto, 2012). We first present the theoretical analysis of the problem and derive the equations of motion of the system. Two independent feedback controllers are then designed to control the system on the ground and in the air. We also present the detailed design of the robot in terms of hardware, electronics, as well as the choice of sensors used to achieve step traversing. Experiments of the robot traversing various stepped terrains are conducted and the results are presented and discussed.

2. DYNAMICS OF THE ROBOT

In this section, we derive the planar equations of motion of the system on ground and in airborne phases to understand the dynamic behavior of the two-wheeled pendulum. When traversing stepped terrain the robot goes through several different dynamic phases, from on the ground to airborne to on the ground again. The changes in the dynamic phases cause discontinuities in the governing equations of motion. To simplify the analysis we have assumed the equations for different phases of motion are separable and can be derived and analyzed independently.

The dynamics during free-fall are modeled using projectile motion with the robot treated as a rigid body. The initial conditions are derived from the state of the robot just before it began falling. Unmodeled dynamics of the system are treated as disturbance forces and be compensated by feedback controllers. The robot is assumed to have reflective symmetry along its vertical axes. This allows the dynamics of

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