Chapter 2
Gait Transition Control of a Biped Robot from Quadrupedal to Bipedal Locomotion based on Central Pattern Generator, Phase Resetting, and Kinematic Synergy

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ABSTRACT
Recently, interest in the study of legged robots has increased, and various gait patterns of the robots have been established. However, unlike humans and animals, these robots still have difficulties in achieving adaptive locomotion, and a huge gap remains between them. This chapter deals with the gait transition of a biped robot from quadrupedal to bipedal locomotion. This gait transition requires drastic changes in the robot posture and the reduction of the number of supporting limbs, so the stability greatly changes during the transition. A locomotion control system is designed to achieve the gait transition based on the physiological concepts of central pattern generator, phase resetting, and kinematic synergy, and the usefulness of this control system is verified by the robot experiment.

1. INTRODUCTION
Humans and animals create various locomotor behaviors, such as walk, run, turn, crawl, skip, and jump, depending on the situation. One objective in robotics is to reproduce such locomotor behaviors using legged robots from the engineering viewpoint. So far, many studies have investigated methods to achieve stable locomotor behaviors for various gait patterns of legged robots. However, their transitions have not been thoroughly examined. In particular, the gait transition from
quadrupedal to bipedal locomotion needs drastic changes in the robot posture and the reduction of the number of supporting limbs. Therefore, the stability greatly changes during the transition and this transition poses a challenging task in robotic studies.

Recently, interest in the study of legged robots has been growing. However, unlike humans and animals, these robots still have difficulties in achieving adaptive locomotion in various situations, and a huge gap remains between them. To create new control strategies, it is natural to use ideas inspired from biological systems. In this study, we construct a locomotion control system of a biped robot to achieve the gait transition from quadrupedal to bipedal locomotion based on the physiological concepts of Central Pattern Generator (CPG), phase resetting, and kinematic synergy, and verify the usefulness of this control system by the robot experiment.

2. GAIT TRANSITION STRATEGY

2.1. Problems in the Gait Transition

Because locomotor behavior is rhythmic motion, a steady gait of a legged robot indicates a stable limit cycle in the state space. Therefore, we need to control the robot to establish a limit cycle to produce a stable gait. Because different steady gaits have different stable limit cycles, a change of the gait pattern implies that the robot state moves from one limit cycle to another. Even if a robot obtains steady gaits, many difficulties remain for the gait transition.

For the gait transition, the following two issues are crucial: (1) because a robot has many Degrees Of Freedom (DOFs), it is difficult to determine how to produce robot movements to connect one gait pattern to another, in other words, how to construct adequate constraint conditions in motion planning; (2) even if the robot establishes stable gait patterns, it may fall over during the gait transition and it is difficult to establish stable gait transition without falling over.

2.2. Solving the Redundancy Problem Based on Kinematic Synergy

In Aoi and Tsuchiya (2007), we investigated the turning behavior of a biped robot, where we produced the turning by changing the gait pattern between straight and curved walking. The turning consisted of two types of limit cycles (straight and curved walking) and the transition between them. Although we dealt with a gait transition, we did not need to solve the redundancy problem. This was because there was a phase at which the robot joint configurations were identical between the robot movements to produce straight and curved walking, as shown in Figure 1a. Therefore, we did not need to create additional robot movements to connect these two gait patterns; we just needed to change the gait pattern at the phase. However, in this study we have to solve the redundancy problem to produce the gait transition of a biped robot from quadrupedal to bipedal locomotion, because no such phase exists for robot movements to produce quadrupedal and bipedal walking (Figure 1b).

Physiological findings suggest the importance of muscle synergies for controlling movements in humans and animals (d’Avella, et al., 2003; d’Avella & Bizzi, 2005; Dominici, et al., 2011; Drew, et al., 2008; Danna-dos-Santos, et al., 2007; Ivanenko, et al., 2005; Ting & Macpherson, 2005; Todorov & Jordan, 2002); these concepts have been analyzed using principal component analysis and factor analysis and are viewed as one solution to handle the redundancy problem in biological systems. Muscle synergy is related to the co-variation of muscle activities. Ivanenko et al. (2004, 2006) reported that, although recorded electromyographic data during human bipedal locomotion are complicated, the data can be ac-