Robotics as a Tool for Gait AND Posture Study

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I. Introduction

The gait (rhythmic motion) and the posture in animals or human have been studied independently for decades as far as the author knows, since it is difficult to measure the activities of posture control exactly while walking. In order to understand the relations between rhythmic motion control and posture control, it is useful to construct the control model of animals or human walking, simulate it using a musculo-skeletal model and compare the simulation results with the results of animals or human experiments. But since it is difficult to simulate friction, collision with ground, effects of elastic materials and so on, we would like to employ experiments using a real machine (robot) in addition to computer simulations. In this article, we discuss the relations between rhythmic motion control and posture control while introducing our studies on quadruped and biped robots. Of course, in order to confirm those hypotheses obtained in robot experiments, we have to arrange animals or human experiments of walking in future.

II. Rolling Motion Feedback to CPGs in Quadruped

In our studies of Tekken series[1], [2], an oscillator-typed CPG (Central Pattern Generator) generated the rhythm of a single leg, and rolling motion of the body was one of feedback signals to CPGs. As a result of this feedback, the timing of landing and lifting in each leg was adjusted and posture of the robot in the lateral plane was well controlled, since the stiffness of joints was high in stance legs and low in swing legs. This could be the first result indicating that posture can be controlled by the adjustment of gait (rhythmic motion generated by CPGs). But since leg loading (ground reaction force) information was not fed-back to CPGs and posture control in low speed walking was not sufficient, Tekken could not walk slowly with long cyclic period.

III. Integration of Rhythmic Motion and Posture Control in Quadruped

This study aims at the design and implementation of a general controller for quadruped locomotion, allowing the robot to use the whole range of quadrupedal gaits (i.e. from low speed walking to fast running). A general legged locomotion controller must integrate both posture control and rhythmic motion control and have the ability to shift continuously from one control method to the other according to locomotion speed. We are developing such general quadrupedal locomotion controller by using a neural model involving a CPG utilizing ground reaction force sensory feedback for both gait generation and posture control. Especially, while using non-oscillator-typed CPGs and generating the self-excited physical oscillation as a result of local feedback, we could be able to integrate sensor-dependent posture control and sensor-driven rhythmic motion control. We used a biologically faithful musculoskeletal model[3] with a spine and hind legs, and computationally simulated stable stepping motion at various speeds combining the neural controller and the musculoskeletal model[4], [5].

IV. Stepping Reflex for Posture Control in Biped

There are huge numbers of studies that measured kinematics, dynamics and the oxygen uptake and so on in human walking on the treadmill. Especially in the splitbelt[1] treadmill walking, a remarkable difference is seen between normal and cerebellar disease subjects in kinematics[6], [7]. A 2D biped robot called 'Tetsuro' was developed to construct the control model of human splitbelt treadmill walking and investigate how it works

A. Stepping Reflex for Speed and Posture Control

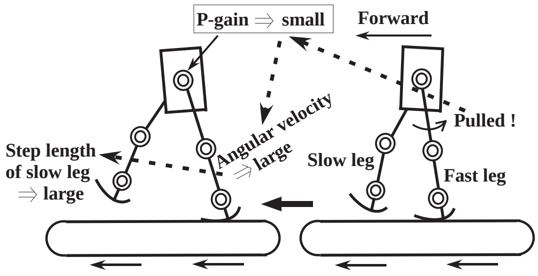
A stepping reflex is the touchdown angle control of a swing leg according to the angular velocity of the stance leg for stabilization of forward speed and posture[8]. Since this touchdown angle becomes the initial angle of the stance leg in the next step, the robot can adjust the motion of the stance leg moving mostly as an inverted pendulum while utilizing gravity. Therefore, the stepping reflex is less energy consumptive than torque adjustment at the ankle joint of the stance leg, which is used for posture control based on ZMP. Consequently, the stepping reflex enables a robot to keep forward speed and posture efficiently against disturbance such as pushing on its back.

The efficient and robust 2D walking on the tied treadmill was achieved by PD control, the cyclic motion trajectory based on the inverted pendulum, and by the forward speed and posture control depending on the stepping reflex[9].

B. Splitbelt Treadmill Walking

The course of the experiment was divided into three stages. Those are the baseline stage, the adaptation stage and the post-adaptation stage. Only in the adaptation stage, the treadmill was in the splitbelt configuration. In every step of walking, the hip joint angle of a leg at lift off: ψ_{off} was measured, and the P-gain of the hip joint of the leg in the next stance phase was updated in the adaptation and post-adaptation stages while comparing ψ_{off} to its average in the baseline stage. This P-gain adjustment was employed on each leg independently. The reason why such P-gain adjustment enables a robot walk on the splitbelt treadmill is shown in Fig.1.

[1]In tied and splitbelt configurations, the speed of left and right belts is same and different, respectively.



(b) next stance phase of the fast leg

(a) stance phase of the fast leg

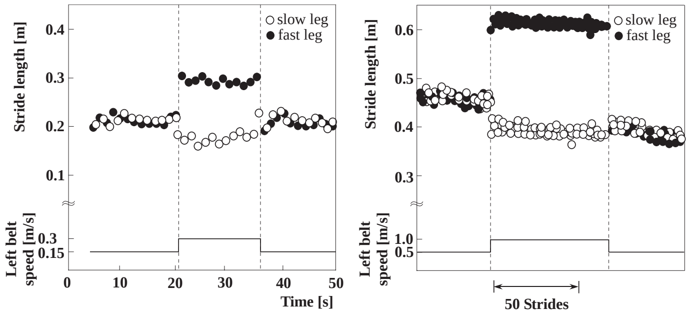
Fig. 1. P-gain adjustment for splitbelt treadmill walking. (a): when the speed of one belt becomes high in the adaptation stage, the fast leg is pulled more backward by the belt in the stance phase and $|\psi_{off}|$ becomes larger. (b): in the next stance phase of the fast leg, as a result of the P-gain adjustment, the stiffness of the hip joint at the fast leg becomes lower, and the fast leg is pulled much more backward. In addition, since the ankle joint angular velocity of the fast leg in the stance phase becomes larger, the touchdown angle of the swing leg becomes larger by the stepping reflex. As a result, the position of the body in the world coordinate is mostly kept constant, and the robot can keep walking on the splitbelt treadmill.

The stride length is defined as the distance traveled by the ankle joint from the time of lift to the time of landing of the leg. The stride length measured in a robot experiment and in human (normal subject) experiments are shown in Fig.2. Each circle in those figures means the value of this index measured at the every walking cycle. In Fig.2, data of a robot experiment and data of human experiments show similar patterns. We could see the same result in the duty ratio[9].

The step length is defined as the distance between positions of the ankle joints of swing and stance legs at the time of landing of the swing leg. The step length difference measured in a robot experiment and in human (normal subject) experiments are shown in Fig.3. In Fig.3, data of a robot experiment and data of human experiments show similar patterns. Here are two interesting subjects. One is that the step length difference gradually became zero in the adaptation stage in spite of the difference in speed of two belts. Another is that the step length difference quickly changed at the switch to the post-adaptation stage even though the speed of two belts became same. This is one of well known phenomena called “negative aftereffect.” We could see the same result in the difference of the ratio of the double legs stance period[9].

While seeing such results of human experiments, Reisman et al.[6] and Morton et al.[7] mentioned that there are two different types of adaptations behind human splitbelt treadmill walking, and called the first one in Fig.2 “reactive adaptations” and the second one in Fig.3 “predictive adaptations.” In contrast to such conclusions of studies on human splitbelt walking, we showed that the single reactive adaptation mechanism is enough to generate two types of indexes. We also showed that P-gain at hip joint of the stance leg is the control parameter of gait adaptations in splitbelt walking.

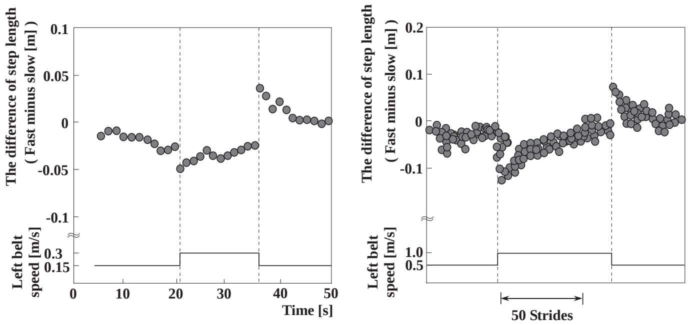
It should be noted that the stepping reflex for posture control plays an important role in the gait adaptations in splitbelt treadmill walking.



(a) a biped robot: Tetsuro (normal subject model)

(b) human (normal subject)

Fig. 2. Results of (a) robot experiment and (b) human experiments (modified from Morton et al. 2006[7]). The stride length in splitbelt treadmill walking are shown. In the adaptation stage of robot and human experiments, speed of belts was 0.15 m/s and 0.5 m/s at the right belt and 0.30 m/s and 1.0 m/s at the left belt, respectively.



(a) a biped robot: Tetsuro (normal subject model)

(b) human (normal subject)

Fig. 3. Results of (a) robot experiment and (b) human experiments (modified from Morton et al. 2006[7]). The step length difference (fast minus slow) in splitbelt treadmill walking are shown.

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