Oscillator-controlled Bipedal Walk with Pneumatic Actuators

K.Tsujita, T.Inoura, A.Morioka, K.Nakatani, K.Suzuki and T.Masuda
Osaka Institute of Technology, Osaka, Japan
tsujita@ee.oit.ac.jp

Abstract

This article deals with development of oscillator controller for the bipedal robot with antagonistic pairs of pneumatic actuators. Periodic motions of the legs are switched between swinging stage and supporting stage according to the phase of oscillators. The oscillators receive touch sensor signals at the end of the legs when the end of the leg touches the ground as feedback signals and compose a steady limit cycle of the total periodic dynamics of the bipedal locomotion. The effectiveness and performances of the proposed controller for the bipedal robot are investigated through numerical simulations and hardware experiments.

Introduction

Locomotion is one of the important functions for mobility. Especially, human bipedal locomotion has high mobility and adaptability to variance of the environment. There have been many researches on bipedal robots driven by DC rotary actuators with the local position feedback controls. However, most of them have high energy consumptions and their knees are always bended; because they are based on high-gain position control of the joints with inverse kinematics for given trajectories of the legs. This type of robot cannot utilize its own dynamics for good energy-efficiency or adaptive adjustment of physical properties of the body mechanism during locomotion. Furthermore, DC rotary actuators have serious difficulties to gain their power-weight ratios, and it makes various limitations of the functions of robots' mobility. Bipedal locomotion has two essential stages in leg motions. One is swinging stage and the other is supporting stage. In the swing stage, the actuator forces are relaxed; stiffness of the joints decreases and becomes passive. When in the supporting stage, stiffness of the joints increases due to generated forces of the antagonistic pair of actuators. By controlling and tuning the stiffness of the joints through the balanced adjustment of the generated force of such pair of actuators, it is expected that the robot obtains adaptability to variances of the environment or of physical properties of the ground surface. Hosoda et al. built a 3D biped robot driven by antagonistic pairs of McKibben actuators. This robot has well balanced design between simple timing controller for switching the leg stages and body mechanism, and realized steady and stable walk. But the control parameters such as time period for each stage are determined based on trial and error. This article deals with development of oscillator controller for the bipedal robot with antagonistic pairs of pneumatic actuators. In the proposed controller, nonlinear oscillators are assigned for each joint. Periodic motions of the legs are switched between swinging stage and supporting stage according to the phase of oscillators. Oscillators compose network architecture and have mutual interactions to each other. These oscillators receive touch sensor signals at the end of the legs when the end of the leg touches the ground as feedback signals. At the contact moment of the leg, the oscillator phase is reset, and swinging stage is forced to change to supporting stage. These dynamic interactions make mutual entrainments between oscillators and compose a steady limit cycle of the total periodic dynamics of the bipedal locomotion. The effectiveness and performances of the proposed controller for the bipedal robot are investigated through numerical simulations and hardware experiments.

Model

Figure 1 shows the schematic model of a planer bipedal robot. The robot has two legs composed of two links, and the main body. The contact model ot the end of the leg is assumed one point support. The motion of this robot is ristricted in the sagittal plane, i.e. it is assume to be 2D motion. Legs are numbered as 1 and 2 for the supporting leg and the swinging one, respectively. The position vector from the origin of the inertial coordinate to the center of mass (C.M.) of the main body is defined as $r_0 = (r_{0x}, r_{0y})^T$.

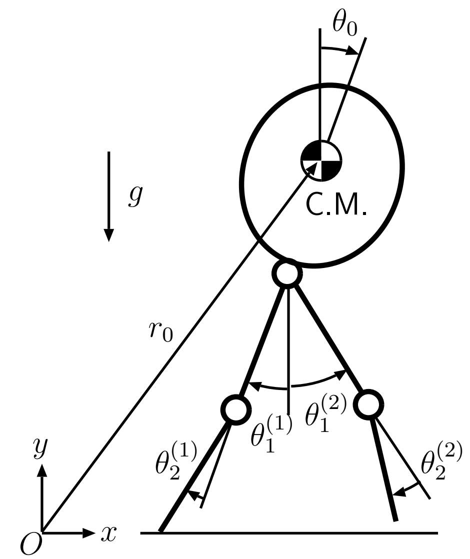

Figure 1. Schematic model of a bipedal robot

The rotatinal angle of the main body, each link of the legs are defined as shown in Figure 1.
The state variable is defined as follows:

$$z = \left[\begin{array}{ccccccc} r_{0x} & r_{0y} & \theta_0 & \theta_1^{(1)} & \theta_2^{(1)} & \theta_1^{(2)} & \theta_2^{(2)} \end{array} \right]^T \quad (1)$$

Equations of motion for state variable z are derived as:

$$M\ddot{z} + H = G + T + E\lambda \quad (2)$$

where M, H, G and E are inertia matrix, nonlinear term, gravity term and Jacobian matrix, respectively. λ is the reaction force at the contact point of the supporting leg. Vector T is composed of the input torques at the rotational joints of the legs $T_j^{(i)}$, $i = 1, 2, j = 1, 2$, which are generated by the antagonistic pairs of pneumatic actuators.

$$T = \left[\begin{array}{ccccccc} 0 & 0 & 0 & T_1^{(1)} & T_2^{(1)} & T_1^{(2)} & T_2^{(2)} \end{array} \right]^T \quad (3)$$

Control Scheme

Figure 2 shows the control scheme of the proposed system. The controller has nonlinear oscillator network. The nonlinear oscillators are assigned to the joints.The antagonistic pairs of pneumatic actuators are driven by the timing signals as functions of oscillator phases. The contact sensor signal is fedback to the oscillator network. This dynamic interactions causes the entrainment and generates stable limit cycle for locomotion.

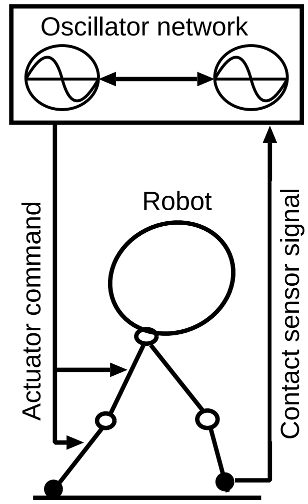

Figure 2. Architecture of the proposed system

Numerical Simulations

Table 1 shows the pysical parameters of the robot. Figure 3 shows the result of the numerical simulation. It indicates the time period of the walking cycle. We can find that the system obtained the stable limit cycle and steay locomotion with the proposed control system.

Length of body	0.20 [m]	Mass of body	1.32 [kg]
Length of thigh	0.25 [m]	Mass of thigh	0.59 [kg]
Length of shank	0.25 [m]	Mass of shank	0.47 [kg]
Total height	0.70 [m]	Total mass	3.44 [kg]

Table 1. Physical parameters of the robot

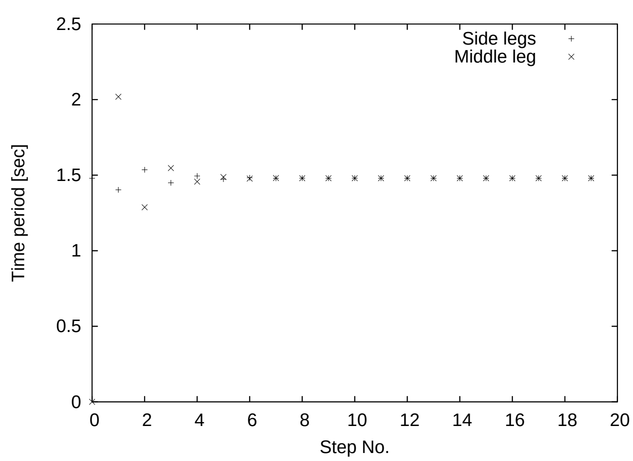

Figure 3. Time peiod of walking cycle for each leg

Hardware Experiments

We implemented walking experiment using the robot shown in figure 4. The hardware model of the robot has tree legs, side legs and one middle leg. Two side legs are connected to each other through a connection rod, and the motion of the side legs are same. This mechanism is to ensure the motion of the robot is restricted in the sagittal plane.

Figure 5 illustrates the architecture of the experimental setup. The host computer controls the electric valves. The contact signal from the touch sensor is input to the host computer through A/D converter. The pressure of the air is adjusted to 0.5 [kPa].

Figure 6 shows the time period of the walking cycle for each leg. We can find that the time period converges to a fixed time period (~ 1.5 [sec]) with a little deviations. This time deviations is caused by the fluctuation of the flatness of the ground surface. The result indicates the efficiency of the developed system.

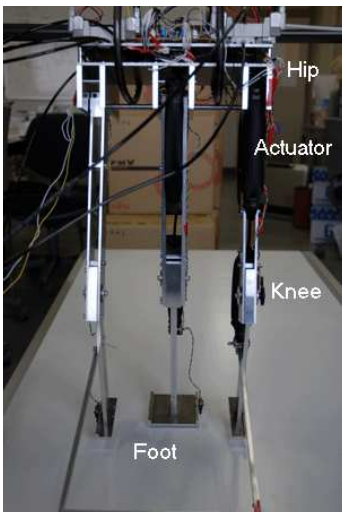

Figure 4. Hardware model

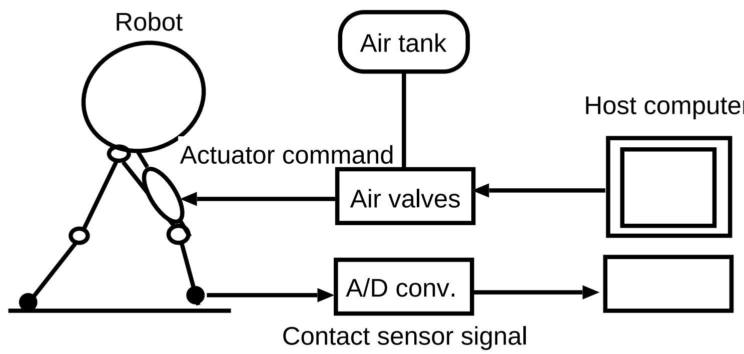

Figure 5. Architecture of the hardware setup

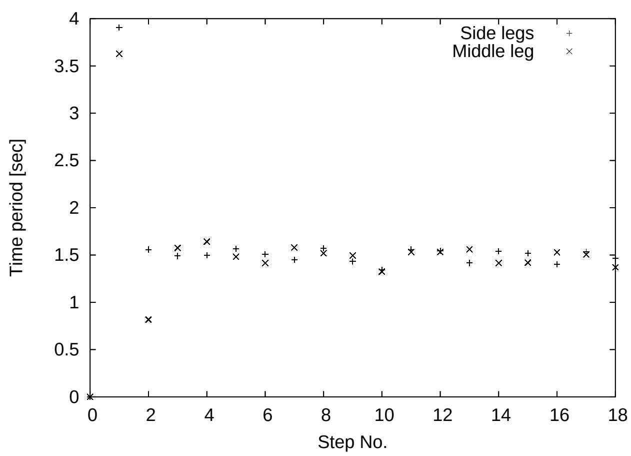

Figure 6. Time peiod of walking cycle for each leg

Conclusions

In this study, we developed a bipedal robot with antagonistic pairs of pneumatic actuators controlled by nonlinear oscillator network. Periodic motions of the legs are switched between swinging stage and supporting stage according to the phase of oscillators. The oscillators receive touch sensor signals at the end of the legs when the end of the leg touches the ground as feedback signals and compose a steady limit cycle of the total periodic dynamics of the bipedal locomotion. The effectiveness and performances of the proposed controller for the bipedal robot are investigated through numerical simulations and hardware experiments.

Acknowledgements

This work has been partially supported by a Grant-in-Aid for Scientific Research on Priority Areas "Emergence of Adaptive Motor Function through Interaction between Body, Brain and Environment" from the Japanese Ministry of Education, Culture, Sports and Technology.

References

T.McGeer, 1990, "Passive dynamic walking," *International Journal of Robotics Research*, Vol.9, No.2, pp.62-82

M. Wisse and J.Frankenhuyzen, 2005, "Design and Construction of MIKE; a 2-D Autonomous Biped Based on Passive Dynamic Walking," *Adaptive Motion of Animals and Machines*, pp.143-154

R.Q.Linde, 1999, "Design, analysis and control of a low power joint for walking robots, by phasic activation of mckibben muscles," *IEEE Trans. Robotics and Automation*, Vol.15, No.4, pp.599-604

K.Ono and X.Yao, 2005, "Simulation Study of Self-Excited Walking of a Biped Mechanism with Bent Knee," *Adaptive Motion of Animals and Machines*, pp.131-142

G.Taga, 1995, "A model of the neuro-musculo-skeletal system for human locomotion: I. Emergence of basic gait," *Biological Cybernetics*, No.73, pp.97-111

Y.Sugimoto and K.Osuka, 2002, "Walking control of quasi-passive-dynamic-walking robot 'Quartet III' based on delayed feedback control," *Proc. of 5th CLAWAR*, pp.123-130

K.Hosoda, T.Takuma and M.Ishikawa, 2005, "Design and Control of a 3D Biped Robot Actuated by Antagonistic Pairs of Pneumatic Muscles," in *3rd Int. Conf. of Adaptive Motion of Animals and Machines*

S.Collins, A.Ruina, R.Tedrake and M.Wisse, 2005, "Efficient bipedal robots based on passive-dynamic walkers," *SCIENCE*, Vol.307, pp.1082-1085

B.Verrelst et al.,"The pneumatic biped "lucy" actuated with pleated pneumatic artificial muscles," *Autonomous Robots*, Vol.18, No.2 pp.201-213