A Pneumatic Biped with an Artificial Musculoskeletal System

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***Abstract*— Understanding the body's musculoskeletal system is one of the ways to understand athletic ability and its development in a vertebrate animal. In this research, we propose a robot with an artificial musculoskeletal system for biomechanics research. In our work, pneumatic artificial muscle is used for the actuator of the robot. Our results show that the robot can achieve vertical jumping, soft landing from a one meter drop and postural control during standing. The robot, which is structurally similar to an animal, is found to be useful for biomechanics study. The musculoskeletal robot also help to illuminate design principles of the robot which can move quickly and skillfully in the real world.**

I. INTRODUCTION

The musculoskeletal system gives animals the ability to move in a huge variety of environments. The mechanical properties of the muscle-tendon and its function in dynamic motion are much debated issue in biomechanics research. It's argued that properties of the musculoskeletal system are utilized in animal locomotion[1], and vertical jumping in human [2].

Recently, numerical simulation of the musculoskeletal system became popular in biomechanics research. However, dynamic motion involves collision and contact which are difficult to model. Thus we propose synthetic approach using a biologically-inspired robot to investigate the role of the musculoskeletal system.

Dynamic motion (such as jumping, landing and running) is characterized by large instantaneous forces and short duration. In such motion, strict design limitations force the robot to have a lot in common with animals. Thus biologically-inspired designs are particularly prevalent for robots which perform dynamic tasks. A lot of bio-inspired legged robot had been proposed. For example, researchers have developed a bipedal walker driven by pneumatic muscle[3], a hopping robot utilize tendon elasticity[4], and a bipedal jumping robot with musculoskeletal leg[5]. However, a robot which has both musculoskeletal structure and various athletic ability has not yet been realized.

In this research, we developed a bipedal robot with an artificial musculoskeletal system. The artificial musculoskeletal system proposed here is the robot architecture based on the biomechanics of the musculoskeletal system. We demonstrate the physical ability and the humanlike properties of the robot through the experiments of postural control, jumping and landing.

II. MUSCULOSKELETAL ROBOT

A. Overview

We developed a bipedal robot with an artificial musculoskeletal system (Fig.1). The robot, weighs about 10 kg and is 1.25 meters tall with the legs extended.

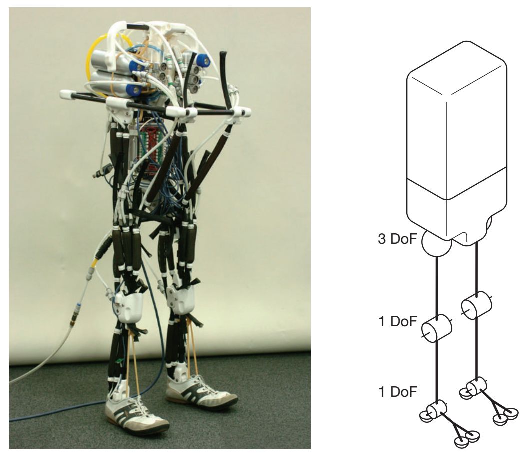

Fig. 1. Bipedal robot with artificial musculoskeletal system.

The musculo-tendon system of the robot corresponding to the anatomical structure of the human (Fig.2). The robot is especially effective at performing explosive movements which require large instantaneous force and is impact-proof.

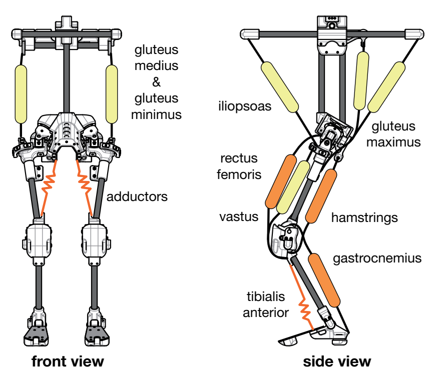

Fig. 2. Configuration of the muscle.

B. Muscular System and Skeletal System

The McKibben type pneumatic artificial muscle is used for the practical implementation of the artificial musculoskeletal system we propose. The pneumatic muscle has similar characteristics in length-load curves with biological muscle. The extremely high power/weight ratio is also good for dynamic motion.

The skeletal frame, which consists mostly of polymer parts, is lightweight and high-impact durable. The range of motion (ROM) allowed at a joint is about the same as a human.

C. Electro-Pneumatic Control System

We apply proportional valves, which transform an analogue input signal into a corresponding air flow, to the electro-pneumatic system instead of conventional on-off valves (Fig.3).

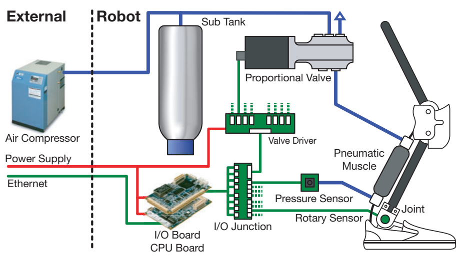

Fig. 3. Electro-pneumatic control system.

The valves and a CPU board are mounted on the robot. The electrical power and compressed air is supplied from external equipment. The robot has a non-contact rotary position sensor on each joint, and a pressure sensor on each muscle.

III. REAL ROBOT EXPERRIMENTS

A. Postural Control

We performed the balance control during bipedal stance by the PID control of each joint, as shown in Fig.4. The joint angles and inner pressure of muscles are recorded. Although the movement of the center of mass is relatively greater than for a stiff robot, the observed sway is similar to human movement reported in biomechanics research[6].

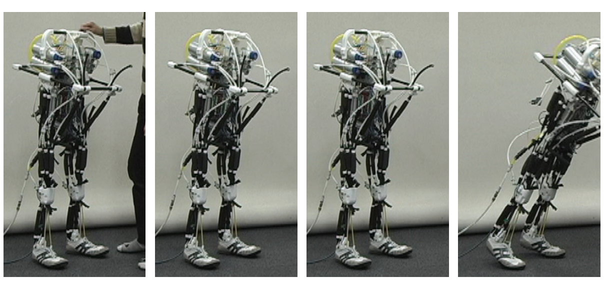

Fig. 4. Postural control during bipedal stance 30 seconds.

B. Vertical Jumping and Soft Landing

The vertical jumping is a simple movement which widely used to study leg power, skills, and characteristics of the musculo-tendon. Our experiments confirmed that the robot can reach jump heights of 0.5 m, as shown in Fig.5.

The robot can land softly from one meter drop by exploiting the compliance and the back-drivability of the body, as shown in Fig.6. These tasks are particularly difficult for the robot when driven by the geared motors because of the large instantaneous forces and short duration.

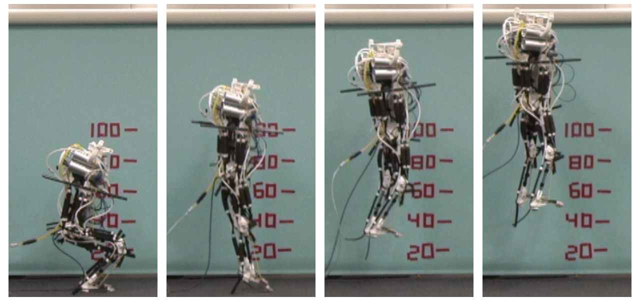

Fig. 5. Vertical Jumping.

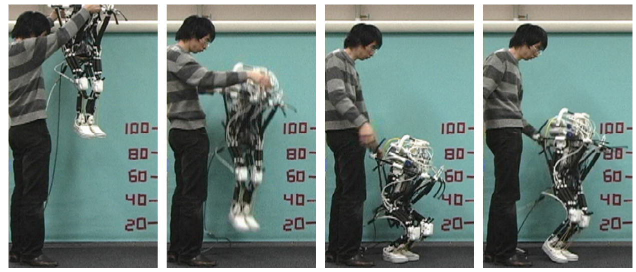

Fig. 6. Soft landing from height 1.0 m.

The physical ability and the anthropomorphic structure of the robot allow us to compare the results with biomechanical abilities of a human.

IV. CONCLUSION AND FUTURE WORK

In this research, we developed a bipedal robot with an artificial musculoskeletal system. We performed postural control during standing, vertical jumping and soft landing motions. We observed body sway during quiet standing which was also reported in humans. In the experiments on jumping and landing, the robot can reach jump height of 0.5m and land softly from one meter drop. This performance is extremely high for a multiple-DoF legged robot. This paper proposes synthetic approach to investigate the biomechanics of the musculoskeletal system using musculoskeletal robot.

We plan to perform various movements with the robot both to obtain detailed data for analysis and to derive design principles of the musculoskeletal architecture.

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