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Author(s)	Takahashi, Ryu; Murakami, Yuki; Hosoda, Koh
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Development of a musculoskeletal hopping robot driven by PAMs with sensory feedback system

Ryu Takahashi*, Yuki Murakami*, Koh Hosoda*
*Adaptive Robotics Laboratory, Graduate School of Engineering Science, Osaka University, Japan
[takahashi.ryu, murakami.yuuki]@arl.sys.es.osaka-u.ac.jp, hosoda@sys.es.osaka-u.ac.jp

1 Introduction

In human locomotion, the central nervous system uses the intrinsic mechanical properties of muscles ingeniously with muscle reflexes. Although the mechanism of muscle reflexes has been revealed anatomically, the activity on neural pathways and its effect during locomotion has not been fully clarified. In this study, we focused on a neuromuscular model that is driven only by muscle reflexes [1]. The model suggested that the rhythm pattern of locomotion can be generated with muscle reflexes if the neural pathways were properly designed. However, few researches of the neuromuscular model have been tested in a real environment.

The purpose of this study is to build a hopping robot with sensory feedback system and to get new insights into effects of muscle reflexes. Here, we introduce a musculoskeletal robot driven by pneumatic artificial muscles (PAMs). We verified that this robot has a hopping ability from a preliminary experiment with a phasic control. This abstract shows a sensory feedback module that can controls PAMs with PID control by changing the target air pressure based on the sensor values. We can construct the neural pathways freely on the robot with this module. Finally, we discuss about a way to generate hopping with the module.

2 Design of musculoskeletal robot

Musculoskeletal robots require an appropriate control method matching the hardware design. Therefore, it is necessary to carefully consider the parameters such as the muscle arrangement. Our robot consists of a three segment leg and a torso with 11 PAMs (Figure 1). Each PAM is driven by supplying and exhausting compressed air with solenoid valves and it generates a force of more than 300N. This hardware design is based on a musculoskeletal robot of our previous research [2]. The height, width and weight of the robot are 970mm, 240mm, 4.70kg respectively. The center of gravity is located under 65mm from hip joint. Vastus lateralis and soleus, called antigravity muscles, are the most important monoarticular muscles to generate enough power of hopping. Thus, we used two parallel PAMs for them. Iliacus and Gluteus maximus contribute to balancing the torso. Three biarticular muscles, rectus femoris, hamstrings, and gastrocnemius contribute to joint coordination.

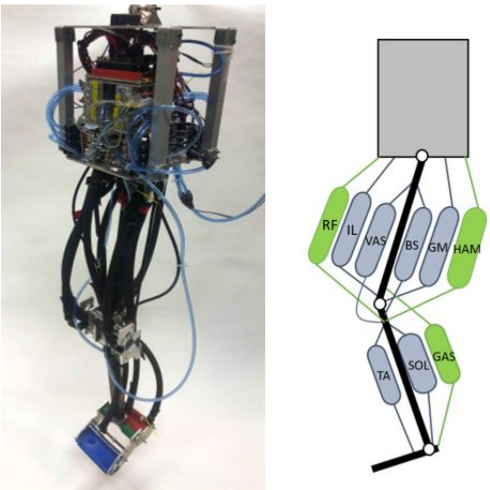

Figure 1: Developed musculoskeletal robot and the muscle arrangement. IL: Iliacus, GM: Gluteus maximus, VAS: Vastus lateralis, BS: Short head of biceps femoris, RF: Rectus femoris, HAM: Hamstrings, TA: Tibialis anterior, SOL: Soleus, GAS: Gastrocnemius. VAS and SOL were implemented by two PAMs.

We conducted a preliminary experiment by using a simple phasic control to verify that the robot can generate a hopping gait with contracting and stretching of its muscles. Figure 2 shows the muscle activation pattern. The robot is released and falls from the hand in a posture determined by initial air supply. Then, the muscles drive with a constant air activation pattern triggered by the lowest point of the posture after landing. The robot detects the point with the internal air pressure change of the vastus lateralis muscle. The muscles are supplied and exhausted air so that they return to the initial air supply states.

The timing of the kicking motion at the ankle joint with soleus and gastrocnemius is very important for the hopping gait. If the ankle extension occurs with moderate delay from the knee joint extension, the robot can jump up vertically by using the elasticity of the musculoskeletal structure. As a result of adjusting the timing experimentally, the highest hopping was appeared by a setting, which the gastrocnemius and soleus muscles were delayed by 150ms and 200ms respectively. Figure 3 shows a snapshot of the hopping gait.

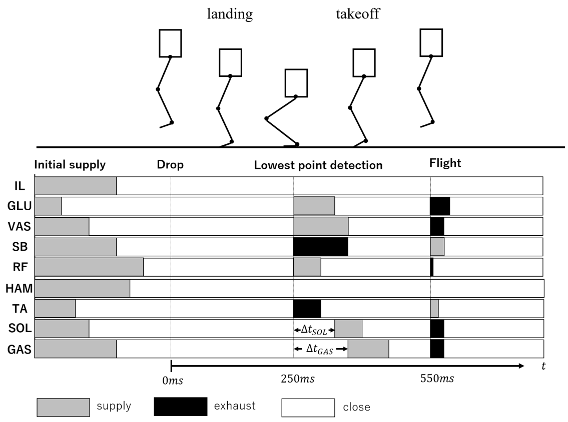

Figure 2: Activation pattern of PAMs

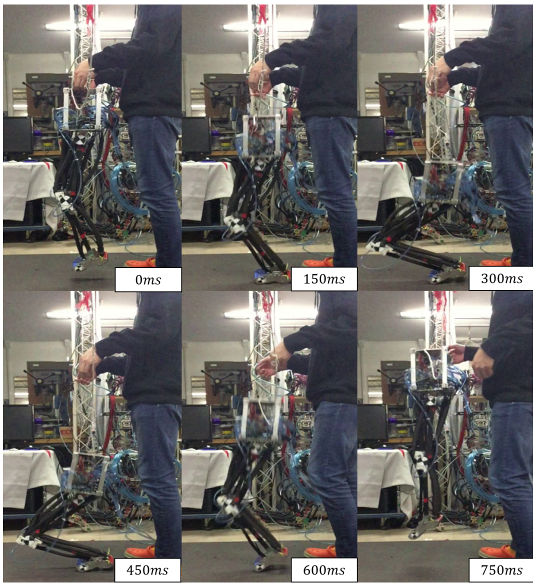

Figure 3: Snapshot of a hopping gait

3 Sensory Feedback Module for PAMs

In this section, we introduce a sensory feedback system that is widely applicable to PAM-driven robots (Figure 4). Each muscle has a wire linear encoder as the length sensor, a self-made load cell as the tension sensor and an air pressure sensor. Each sensor value and the drive current can be updated at 1kHz. Compared to the human nervous system, the wire encoder corresponds to a muscle spindle and the load cell corresponds to a Golgi tendon organ. The sensory feedback system is consist of three steps. (1) Correction of sensory information, (2) spinal reflex mechanism, and (3) PID control of the PAMs' air pressure. In the first step, sensory information of each muscle is collected from the three sensors. Tension and length information are modified with gains (G_F, G_L) specific to each muscle. The second step is the spinal reflex mechanism, where the collected sensory information is input to the reflex rules. The output of reflex rules is normalized and finally output as the target air pressure (P_d) of each muscle. A reflex rule is a set of modules created by a system designer to generate locomotion; it is a mathematical integration of sensory information, as shown in Geyer et al [1]. P_d corresponds to the number of muscle fibers mobilized by the motoneurons. In the third step, the actual air pressure P_a is measured by the air pressure sensor, and the PAM is driven by PID control of the drive current of the valves so that the P_a follows P_d. This system can be applied to various PAM-driven robots by changing the design of the reflex rules according to the desired locomotion.

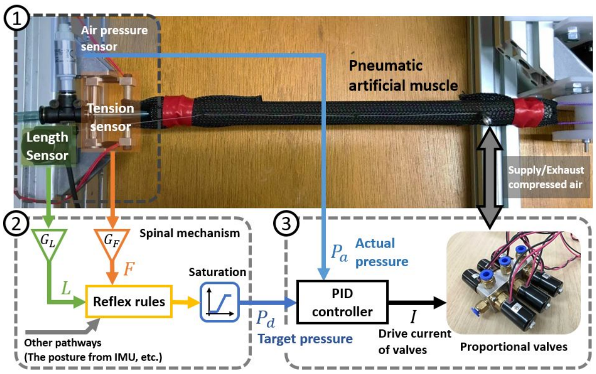

Figure 4: Schematic view of a sensory feedback system for PAMs.

4 Discussion and Conclusion

A motor-driven robot using a neuromuscular model has been proposed as a robotics approach to verify the method of Geyer et al. in a real environment [3]. However, the leg dynamics reproduced by the motor might be quite different from that produced by the human motor control because humans use antagonistic muscle groups to drive their joints. As can be imagined in the movement of the arms, there is a certain directions that can easier to move depending on the posture. In this paper, we showed the hopping ability of a PAM-driven robot and the sensory feedback system that can be implemented in the robot. PAM has the same output style as human muscles, which are flexible and can only move in a straight line (see the detail comparison in the paper of Omid et al. [4]). A robot with a musculoskeletal structure composed of PAMs can structurally reproduce the redundant degrees of freedom of the human body, and may be able to discover the principles of hopping that has not been found in physical simulations or motor-driven robots.

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