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On brainless-control approach to soft bodies: a novel method to generate motion patterns by pneumatic reflex devices ⋆

Yoichi Masuda * **Masato Ishikawa** *

* *the Department of Mechanical Engineering, Osaka University, 2-1, Yamadaoka, Suita, Osaka, 565-0871, Japan (e-mail: masuda@mech.eng.osaka-u.ac.jp, ishikawa@mech.eng.osaka-u.ac.jp).*

Abstract: Controlling soft robots is a challenging task, for it is embedded in a highly coupled system composed of elastic body, controller, and environment. The system is often unsteady, uncertain, and unpredictable, and it is even difficult to define clear boundaries among the body components and the environment. For generating periodic motion patterns of elastic bodies without determination of a detailed system model, we introduce a method called brainless control approach. In our previous study along this approach, we discovered an interesting phenomenon that a musculoskeletal quasi-quadruped robot emerges high-speed running motion without any electronic sensor or microprocessor. In other words, we did not equip it with any explicit controller; instead, we designed the mechanical "reflex" devices and embed them in the distal parts of the robot body. This result was surely suggestive, however, there still remain a lot of unsolved questions such as why and how the robot can self-organize its motion pattern between the joints and the limbs. In this paper, we investigate fundamental characteristics of this pneumatic reflex device, to establish a basis for further discussion concerning the self-organizing principle.

Keywords: decentralized control, walking, robot control, pneumatic systems, actuators

1. INTRODUCTION

Motion control of robots under unpredictable environments is still a primary issue in robotics. Among them, controlling soft robots is a challenging task than rigid ones. Soft robots under the unpredictable environment are embedded in a highly coupled system composed of its body, controller, and environment. Not to mention the difficulty of controlling its elastic body, they are significantly affected by the environment due to their highly elastic and deformable characteristics Rus (2015); Thuruthel (2018). Therefore, it is difficult to define clear boundaries among the coupled system of the body components and the environment. For handling such messy systems, there are two options to achieve desired control tasks: building a precise model or looking for another way to avoid it for controller design without a model. This article describes a model-less approach, which can be a candidate for the latter, to generation of adaptive motion patterns of robots.

The strategy we take to generate motion patterns of robots is an autonomous decentralized approach by Masuda (2017) that exploits the dynamics of the body and the environment. In the authors' latest work in Masuda (2020), we discovered a phenomenon in which a musculoskeletal quasi-quadruped robot emerged high-speed running motion. The robot with the reflex devices generated an alternating gait, and achieved inter-muscular coordination and a leg trajectory generation autonomously, without a model. A key element of the robot is a novel decentralized actuator module, called the pneumatic reflex devices. A remarkable point of this work is that the reflex devices are composed of purely mechanical elements (pneumatic muscle and valve); hence, the robot has no microprocessor or explicit controller. Since the robot does not have any computer that corresponds to the animal brain, we call this design method the brainless control approach Masuda (2017). The reflex devices are embedded in distal parts of the body, therefore, they drive the distal joints so that they respond reflexively to reaction forces from the environment. As a result, phase differences of each module are self-organized due to the interaction between the chain of reflexes through the body-environment dynamics.

In Masuda (2020), we observed the interesting self-organization phenomenon that can be a key to model-less motion control. However, mechanisms behind the self-organization are still not clear. In this paper, to investigate the source of the self-organization, we discuss the fundamental characteristics of the reflex devices. Two experimental results suggest that the reflex device has two functions that contribute to the self-organization. The first function is rhythm generation that produces temporal rhythmicity of limbs, and the second is pattern formation that adjusts phase difference between the left-right limbs.

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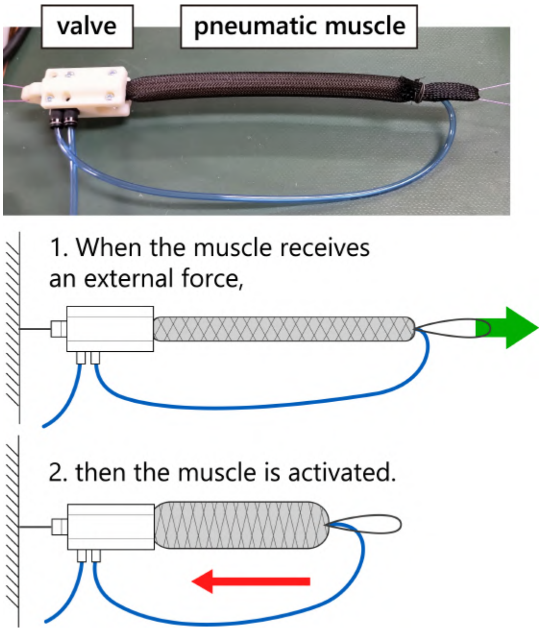

Fig. 1. The pneumatic reflex device.

2. WALKING PHENOMENON ARISING FROM PNEUMATIC REFLEXES

For generating motion patterns of the robot without a model, we developed a novel decentralized actuator module, called the pneumatic reflex devices Masuda (2020). Fig. 1 shows the overview of the reflex device. The design of this device is based on the reflex function of animals. The device is composed of an artificial sensory organ (pressure-sensitive valve) and an artificial muscle (pneumatic actuator). Although a constant air pressure is applied to the valve, initially, the valve is closed, and the airflow is blocked. When the muscle receives an external tensile force from the body and environment, then the valve turns on, and the air pressure from the valve activates the pneumatic muscle.

Fig. 2 (A) shows the musculoskeletal quasi-quadruped robot with the reflex devices. The robot is composed of two fore-wheels and two hind-limbs. Each limb consists of three links and three joints (Fig. 2 (B)), and one of which is constrained by a pantograph mechanism. The reflex devices are implemented to the knee and the hip joint, and each joint is extended when the valve turned on (the muscle shrinks). Conversely, when the valve is turned off, each joint is flexed by the spring attached to the joints. For more detail on the reflex devices, see Masuda (2020). In the walking experiment Fig. 2 (C), the robot generated an alternating gait and achieved inter-muscular coordination and a leg trajectory generation autonomously.

In the experiment, although we observed the autonomous three-dimensional running of the musculoskeletal robot, the mechanisms behind the self-organization are still not clear. To investigate the source of the self-organization, in the following chapters, we show two fundamental characteristics of the reflex devices. The first is rhythm generation that produces temporal rhythmicity of limbs, and the second is pattern formation that adjusts phase difference between the left-right limbs.

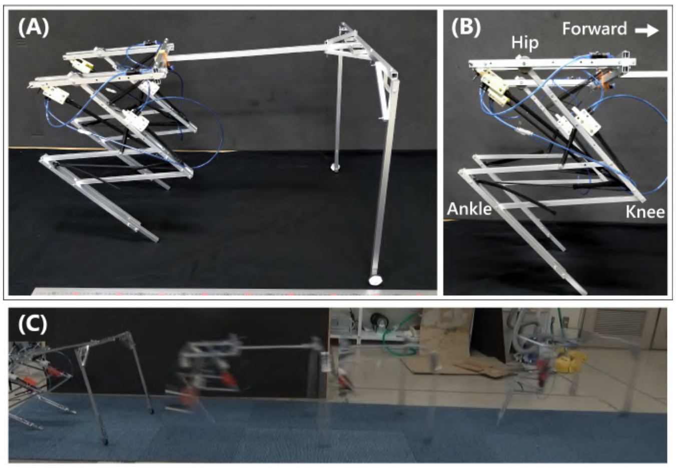

Fig. 2. (A) Quasi-quadruped robot with the reflex devices Masuda (2020). (B) Each limb consists of the hip, knee, and ankle joints. (C) The robot generated an alternating gait, and achieved inter-muscular coordination and a leg trajectory generation autonomously.

3. RHYTHM GENERATION OF REFLEX DEVICES

To investigate the mechanisms behind the rhythm generation, we conduct a fundamental experiment. Fig. 3 (A) shows the setting of the experiment. In the experiment, we applied a 0.3MPa constant pressure to the reflex device with one end fixed and applied a load of 500g. The natural length of the pneumatic muscle is 300mm.

Fig. 3 (B) shows a time response of the length of the pneumatic muscle. When we applied the constant pressure to the reflex device, after the muscle shrinks once, and generate a periodic motion. The result suggests that the mechanism behind the rhythmicity is the inertia of the limbs and dynamics of the reflex devices. Namely, when the valve is turned on by applying a ground reaction force, the limb is extended by the muscle and kick the ground. After the extension, the valve is turned off because of a loss of the reaction force, and the limb begins to flex with a spring. When the leg finished contracting, the inertial force applied to the muscle turns on the valve, as a result, the next contraction starts.

4. PHASE ADJUSTMENT BETWEEN REFLEX DEVICES

The second function in the system is the phase adjustment. In the walking experiments in Masuda (2020), the phase difference of the left-right limbs converges from in-phase to anti-phase. Therefore, we assumed that there is some mechanism that adjusts the phases of the limbs.

To investigate the mechanisms, we conduct a running experiment under the same conditions as Masuda (2020). Fig. 4 shows the time response of the joint angles (hip, knee, and ankle joints of the left limb) during an experiment. The vertical solid lines indicate the timing of the touch-down of the foot, and the dotted ones indicate the timing of the lift-off. The gray bands indicate the periods during the stance phase of the left foot. In the figure, before the touch-down, (A) the knee muscle is activated, and after

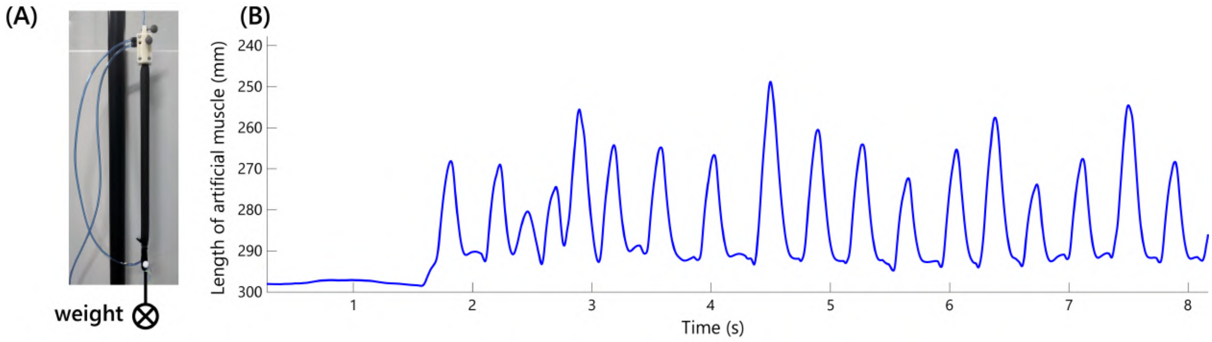

Fig. 3. Rhythm generation of reflex devices. (A) The initial setting of the experiment. (B) A time response of the length of the pneumatic muscle.

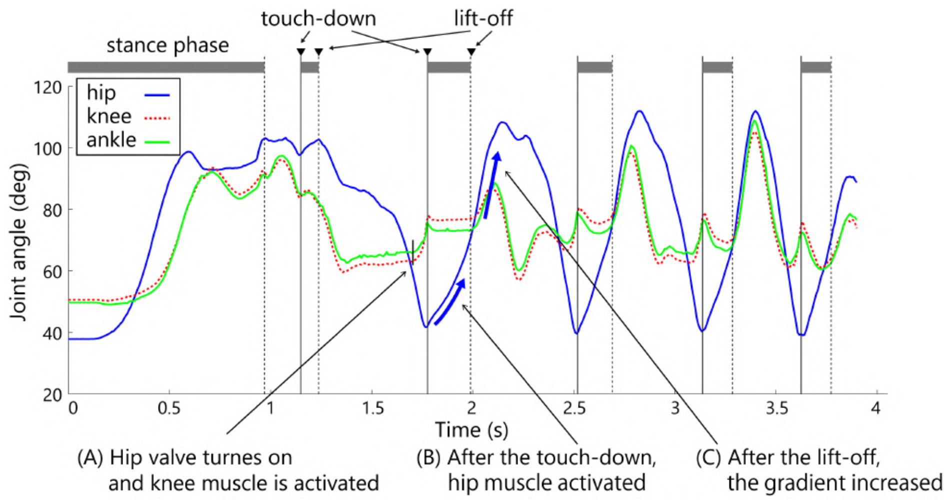

Fig. 4. Joint angles of quasi-quadruped robot during a running.

that, (B) the hip muscle is activated [1]. After the touch-down, the reaction forces from the ground inhibits the knee and ankle extension. Moreover, due to the inhibition of the hip extension by reaction forces, (C) gradient of the hip angle changes around the lift-off.

From the result, we observed that the pneumatic muscle in the reflex device delays the limb motion according to the reaction forces from the ground. In other words, the reflex device has a function that the reflex device to keep the phase of the limb while receiving a large reaction force from the ground. It is considered that this function converges the phase difference between the limbs to a gait in which the reaction force was appropriately distributed.

5. CONCLUSION

In this paper, we discussed the mechanisms behind the running phenomenon of the musculoskeletal robot with the pneumatic reflex devices. To clarify the mechanisms, we conducted two experiments with the reflex device by focusing on two functions: the rhythm generation and the pattern formation. The first experiment suggested that the rhythmicity is produced by the inertia of the limbs and dynamics of the reflex devices. The second suggested that the force–velocity relationship of the pneumatic muscles coordinate the patterns of the limb motions. In future work, we will conduct some experiments and analysis to clarify further the principles underlying the robot.

[1] The timing of the muscular activity is produced by the reflex pathways that are designed to interconnect the hip and knee reflex devices. For more detail, see Masuda (2020)

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