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Artificial Receptor for Brainless Balancing Control

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1 Introduction

Conventional robots based on models and fast computation have been developed for closed systems such as factories and laboratories. However, robotics is faced with difficulties of motion control on open systems containing unstructured and unlimited environments. Because the computational resources for motion control and the algorithms written by controller designers are limited, making it difficult for robots to cope with all the unlimited environments.

An alternative approach to model-based robotics is interaction-based robotics, including embodied intelligence [1] and soft robotics [2]. Researchers of interaction-based robotics hope the robot's motion to be controlled almost automatically by a well-designed relationship between the body and the environment. If we can design and utilize the interaction between the body and the environment, we may be able to incorporate the unlimited environment into the system, thus potentially breaking the limitation of computational resources.

This research aims to establish fundamental technologies for designing the interaction between the environment and the body. The authors have proposed a design method called the brainless control approach, in which we embed some mechanical stimulus-response devices throughout the robot body and utilize the synchronization phenomenon between the devices to generate the robot motion. An essential feature of the approach is that the stimulus-response device comprises purely mechanical elements without a computer. The mechanical devices actuate the robot body while adjusting the robot motion in response to stimuli from the body–environment dynamics. As a result, the devices, the whole robot body, and the environment are entrained into a dynamically reasonable motion. This approach makes it possible to implement autonomous decentralized systems with many real-time adaptive stimulus-response loops throughout the body, such as reflex systems in animals.

In our previous research, we developed a mechanical artificial receptor device to reproduce the components of the reflex system in quadrupeds [3, 4]. By embedding the receptor devices in a musculoskeletal robot and reproducing a cat's reflex circuit in a pneumatic system, the robot generated leg trajectory and alternating gait automatically. However, the conventional receptor device has only a discrete control function that outputs air pressure when the receptor receives external force and stops outputting air pressure otherwise. This paper reports a receptor device that continuously adjusts air pressure according to the external force applied to the device. To evaluate it, we perform a simple experiment in a balance control task using a musculoskeletal biped robot.

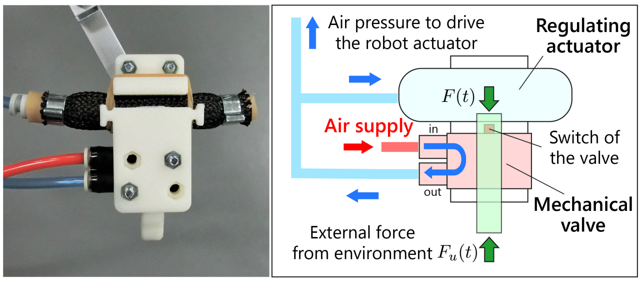

Figure 1: Overview of the artificial receptor.

2 Artificial receptor device

Animals have sensory receptors that detect external force. If the receptors receive force from the outside world, they send motor commands to the muscles through nerves, and the muscles contract reflexively. In this paper, we report on an artificial receptor device that mimics the function of these force receptors.

Fig. 1 shows the artificial receptor device. This device consists of a mechanical valve (normally open) and a regulating actuator (a small pneumatic actuator that regulates the airflow in the valve). In addition, the other actuator to drive the robot body is connected parallel to the regulating actuator. The valve receives constant air pressure from an air supply, and if the push switch of the valve receives no external load, the input air pressure is output directly through the valve. However, if the switch of the valve receives force above a certain threshold, the valve stops the airflow.

We briefly explain the principle of the device operation. If the artificial receptor receives air pressure from the air supply, the air pressure inflates the two actuators connected to the output port of the valve. What is important here is the relationship between the inflation of the regulating actuator and the opening and closing of the valve. If the regulating actuator inflates, force $F(t)$ generated by the actuator is transmitted to the push switch of the valve. And then, if the force transmitted to the valve exceeds a certain threshold $\bar{F}$, the valve closes, the pneumatic output stops, and the inflation of the regulating actuator stops. If the force transmitted to the valve exceeds a certain threshold $\bar{F}$, the valve closes, the pneumatic output stops, and the inflation of the regulating actuator stops. Conversely, when the force transmitted to the valve falls below the threshold $\bar{F}$, the valve opens to restore air pressure. In other words, the force $F(t)$ generated by the regulating actuator is always balanced with the valve-specific threshold $\bar{F}$ and regulated to satisfy the equation $F(t) = \bar{F}$.

Next, let us consider the case where external force $F_u(t)$ from the environment is applied to the switch of the valve. In this case, the switch of the valve receives resultant force $F(t) + F_u(t)$ from the regulating actuator and the environment. By the same mechanism as when there is no external force from the environment, the resultant force $F(t) + F_u(t)$ balances the valve-specific threshold $\bar{F}$ and satisfies the equation $F(t) + F_u(t) = \bar{F}$. From a different perspective, this means that the force $F(t)$ generated by the regulating actuator is controlled to satisfy the equation $F(t) = \bar{F} - F_u(t)$ according to the external force $F_u(t)$ applied to the switch of the valve. Since the regulating actuator and the actuator to drive the robot body are connected in parallel, the pressure in the actuator is continuously adjusted according to the external force $F_u(t)$.

3 Experiment

We conduct a simple experiment to evaluate the artificial receptor. Fig. 2 shows a musculoskeletal biped robot and its structure. We constrain the robot in the coronal plane using a support rod. We attached two artificial receptors to the tips of both toes and connected the output ports of each receptor to the extensor muscles of the ipsilateral limb. If the body tilts and the ground reaction force applied to the artificial receptors increases, the robot resists the reaction force by increasing the air pressure in the extensor muscle and maintains its balance. To verify the balance control by the device, we applied a disturbance by the hand from the side of the robot in a standing posture and measured the body tilt from the ground by a motion capture system. We compare the results of two experiments: one is controlled by the artificial receptor and the other in which a constant air pressure was applied to the extensor muscles of both legs. In both experiments, we adjusted the initial air pressure inside the extensor muscles to be 0.25 Mpa before the disturbance.

Fig. 3 shows the experimental results. The blue line indicates the body tilt controlled by the receptor, and the red indicates the result without the receptor. Note that there are initial errors because of a dead zone near the origin. The figure shows that the artificial receptor quickly returns the robot posture to the initial one.

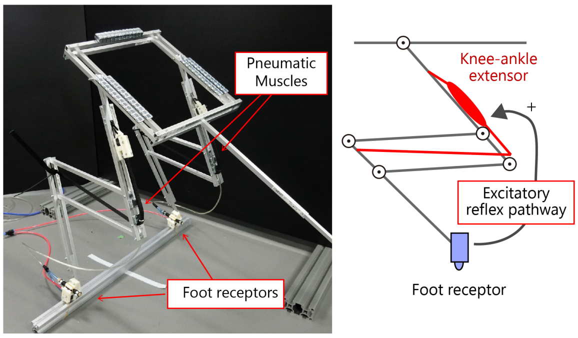

Figure 2: Overview of the biped robot. When the foot receptor receives reaction force, it drives the extensor muscle.

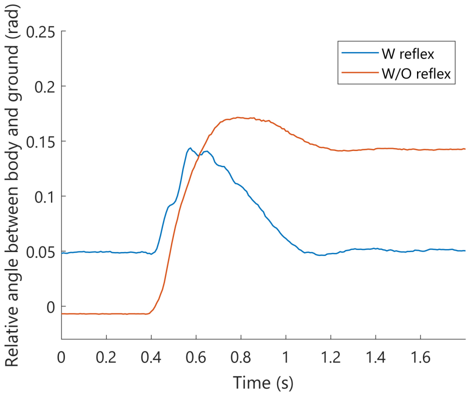

Figure 3: Experimental results.

4 Conclusion

This paper reports a receptor device that continuously adjusts air pressure according to the external force applied to the device. We performed a simple experiment in a posture control task using a musculoskeletal biped robot. The result suggests a possibility of the posture control of legged robots without any computers.

Acknowledgement

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