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A Humanoid Robot with Anatomy Trains that can Passively Sustain Standing Postures

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1 Introduction

What roles the musculoskeletal structures of dynamical systems such as vertebrates and multi-joint musculoskeletal robots play in sustaining the standing posture is an important question in various academic fields, including biomechanics, anatomy, biology, and robotics. Here, we focus on Anatomy Trains (hereafter called "ATs") [1], which are the wide-range mechanical connections between multiple muscles. In an AT, muscles are not only attached to bones but are connected in broad areas by elastic connective tissue, such as tendons, ligaments, and fasciae. Therefore, multiple joints are connected via ATs.

Several studies have suggested that musculoskeletal robots can sustain standing posture using the multi-joint connection. Ito *et al.* [2] developed a crocodilian hindlimb robot that sustained the standing posture using a musculotendon structure over multiple joints. In addition, Badri-Spröwitz *et al.* [3] developed an avian-type running robot that supported body weight and absorbed shock in the stance phase using spring tendons over multiple joints.

Although the above studies have referred to the intralimb multi-joint connections in robots, little study has been done to investigate multi-joint connections over the whole body, including legs, a trunk, and a head, in robots. However, from anatomy and physical therapy perspectives, Myers [1] has suggested that humans sustain the standing posture in the sagittal plane using the following three kinds of ATs; the Superficial Back Line (hereafter called "SBL"), the Superficial Front Line (hereafter called "SFL"), and the part from the head to the trunk of Deep Front Line (hereafter called "Local DFL"). Inspired by the above suggestion from Myers, we focus on whether there exists the set of physical parameters that allows a musculoskeletal robot equipped with artificial SBLs, SFLs, and local DFLs to sustain the standing posture. Here, the physical parameters are the weight and size of the robot, the arrangement of ATs, the dynamic characteristics of each material, and so on.

One of the important problems in installing whole-body ATs in robots is the difficulty in determining the set of physical parameters that allows a musculoskeletal robot with ATs to sustain the standing posture. This problem results from the probability that when a torque of a joint is changed by parameter tuning, the torques of other joints can be changed by ATs.

In this study, we aim to show that there exists the set of physical parameters that allows a humanoid robot equipped with SBLs, SFLs, and Local DFLs to achieve the following goal. The goal is that with the same physical parameter set, the robot passively sustains multiple standing postures and absorbs external shock. For this goal, we developed a humanoid robot "PEARL II," which had SBLs, SFLs, and Local DFLs.

2 Method

2.1 Musculoskeletal Structure of PEARL II

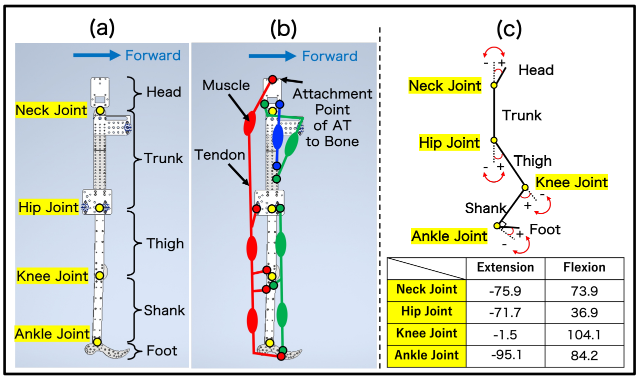
PEARL II had no actuators. This setting allows us to ignore motor commands from controllers like nervous systems that occur in humans. We describe the details of the musculoskeletal structure of PEARL II below.

Regarding the skeleton of PEARL II, as shown in Figure 1(a), the skeleton was composed of links of a head, a trunk, thighs, shanks, and feet. Thus, as shown in Figure 1(b), muscles that start and stop within the same link were omitted. Additionally, as shown in Figure 1(a), the rotation axis of each joint of PEARL II was limited to the pitch direction to focus on the standing posture in the sagittal plane. The number of joints of PEARL II was seven, consisting of the neck, hip, knee, and ankle joints.

Regarding the ATs of PEARL II, the ATs were made of rubber fiber and polypropylene cord. Rubber fiber can effectively generate multiple standing postures and absorb shock because rubber fiber can be stretched while generating tension. On the other hand, polypropylene can effectively generate strong tension because polypropylene has strong elasticity. As for humans, their muscles have the characteristics of contraction by elongation. In addition, connective tissues, that is, tendons of humans, have strong and high elastic characteristics. Therefore, the muscles of PEARL II were made of rubber fiber cord, and the tendons of PEARL II were made of rubber fiber and polypropylene cord. Then, the muscles and the tendons were sewn together to compose each AT. Here, as shown in Figure 1(b), several muscles were connected in series with tendons, some of which have one or more bifurcation points. The branches of tendons were connected to bones.

2.2 Determination of Physical Parameter Set

By trial and error, we determined the set of physical parameters that allowed PEARL II to passively sustain multiple standing postures and absorb external shock. Here, the weight and height of PEARL II were approximately 1.8 kg and 900 mm, respectively.



	Extension	Flexion
Neck Joint	-75.9	73.9
Hip Joint	-71.7	36.9
Knee Joint	-1.5	104.1
Ankle Joint	-95.1	84.2

Figure 1: The musculoskeletal model of PEARL II in the sagittal plane. (a), (b), and (c) show the skeleton, the musculoskeletal structure, and the movement range of each joint (unit: degree), respectively. The red, green, and blue lines in (b) illustrate SBL, SFL, Local DFL, respectively.

3 Result

3.1 Sustenance of Multiple Standing Postures

We manually made PEARL II statically stand up. Then, as shown in Figure 2(a)(b), PEARL II sustained multiple standing postures. In contrast, PEARL II, without the three ATs immediately fell down. It can be presumed that the ATs containing muscles made of rubber fiber and tendons mainly made of polypropylene enabled PEARL II to keep the range of motions of each joint while transmitting the tension to sustain multiple standing postures.

3.2 Absorption of External Shock

We manually input an instant forward force to the PEARL II's head under Figure 2(b) condition. Then, as shown in Figure 2(c), the upper body mainly vibrated and converged in several seconds, and consequently, PEARL II sustained the standing posture. In contrast, under Figure 2(a) condition, PEARL II fell down immediately when it received external shock. It can be presumed that the joint angles were the decisive factor for the stability of the standing postures. Under Figure 2(b) condition, the ATs can generate high elasticity to distribute the torque on the neck joint to other joints. Furthermore, the base of support can be expanded, which is the area around the outside edge of the sections of the feet in contact with the ground.

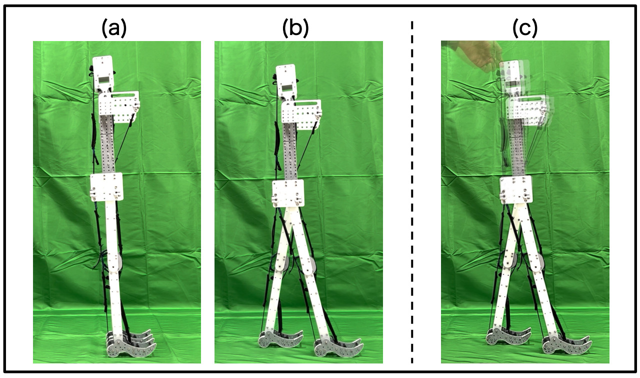


Figure 2: Standing postures of PEARL II. (a) and (b) show the passive sustenance of the static standing posture with both legs together and open, respectively. (c) shows the process of external shock absorption.

4 Conclusion and Future Work

In this study, we showed that there exists the set of physical parameters that allows a humanoid robot equipped with SBLs, SFLs, and Local DFLs to passively sustain multiple standing postures and absorb external shock.

In future work, it is important to research how each joint of the whole body absorbs external shock. Furthermore, a study of the relationship between the physical parameters, the joint angles, and the stability of standing postures should be systematically conducted.

Acknowledgments

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