Three-Dimensional Muscle Arrangement and Dynamic Walking of Musculoskeletal Humanoid

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Abstract: Humans have the highly-complicated musculoskeletal body structure and perform adaptive behavior. To investigate the advantages of this structure, we built a whole-body musculoskeletal humanoid with pneumatic artificial muscles. The skeletal structure and muscle arrangement of the robot are three-dimensionally designed to be similar to those of humans, especially in the lower body. Taking advantage of the human-like structure of the robot, we conducted a walking experiment. To make muscle activation patterns, we use a human EMG patterns. As a result, if the structure of the robot is close to that of humans, we found the motion of the robot can be easily created and realized dynamic walking.

Keywords: Biomechanics, Musculoskeletal system, Humanoid robot, Pneumatic artificial muscle, Dynamic Walking

1. INTRODUCTION

Humans have the highly-complicated musculoskeletal body structure with the many joints and muscles. Humans are able to utilize the complicated body and to perform adaptive behavior such as walking. The complex human body structure might have some reasons, because ”Nature creates nothing without a purpose”(Aristotle, 350 B.C.E). One of the advantages of the musculoskeletal system, bi-articular muscles have the function that dissolve contact tasks with open loop control [1]. If we understand advantages of the musculoskeletal structure and apply them to robots correctly, we can enhance the performance of the robot.

In biomechanics, some human body structures have been mimicked and some musculoskeletal humanoid robots have been developed in recent years. The musculoskeletal robots with pneumatic artificial muscle realized various dynamic tasks [2, 3]. However, these robots have only basic muscles in the lower body or these muscles are attached only for pitch, roll, or yaw movements. The contraction forces of most of the human muscles exert influences on pitch, roll and yaw movements simultaneously. In addition, for humans, even the single movement such as the hip flexion is realized in coordination of several muscles around the hip joint. Since human musculoskeletal structure has redundant muscles attached three-dimensionally, we should take it into account in designing musculoskeletal robots.

In this study, under the assumption that musculoskeletal robot performing three dimensional movements should have three dimensional muscle arrangement, we built a musculoskeletal humanoid robot driven by pneumatic artificial muscles attached three dimensionally. The robot’s musculoskeletal structure is highly similar to that of humans, especially in the lower body. In this paper, we introduce the design of the robot and its three-dimensional muscle arrangement. In addition, we make a walking motion taking advantage of human-like musculoskeletal body and conduct a walking experiment.

2. PNEUMATIC ARTIFICIAL MUSCULOSKELETAL HUMANOID ”PNEUMAT-BS”

We developed a musculoskeletal humanoid robot ”Pneumat-BS” actuated by pneumatic artificial muscles. Fig. 1 shows the appearance of the robot, its DOF and the arrangement of the artificial muscles. The overall height

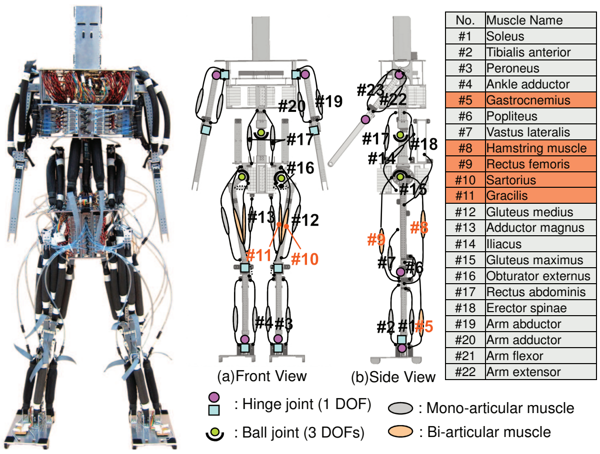

Fig. 1 A musculoskeletal humanoid robot ”Pneumat-BS”. Left: Photograph. Right: DOF and muscle arrangement.

of the robot is 1181 [mm] and the weight is 10.1 [kg]. The link length and the center of gravity of the robot are designed to be the same ratio as that of humans. This robot has 21 DOFs, and 44 pneumatic artificial muscles are attached to the robot in total. Supplying and exhausting compressed air from an air compressor is controlled by on-off electric valves. As the sensor configuration, there are two acceleration sensors (3-axes) on the head and waist, two gyro sensors on the head (pitch, roll) and 8 force sensing resistors on the four corners of both feet.

The robot has complex body structure, including not only mono-articular muscles but also bi-articular muscles. In particular, the hip joint of the robot is driven by 9 muscles (♯8∼♯16). Using PE braided lines, we arrange these muscles three dimensionally (Fig. 2). The three-dimensional arrangement of muscles is important in dealing with three-dimensional movements. For example, sartorius (♯10) is a bi-articular muscle which has the function of knee flexion, hip flexion, hip external rotation, and hip abduction. This muscle generate pelvic rotation at the beginning of the swing phase. Pelvic rotation make the step width narrow and make stride long (Fig. 3). It makes the walking more stable and efficient.

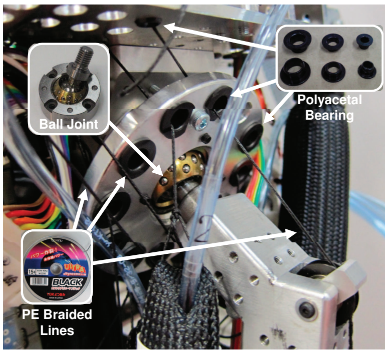

Fig. 2 Around hip joint of Pneumat-BS.

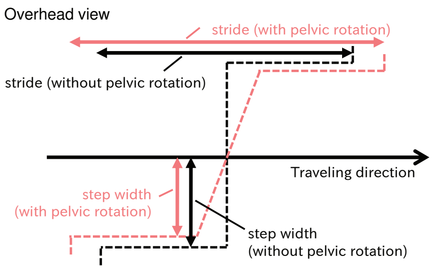

Fig. 3 Effect of the pelvic rotation.

3. WALKING EXPERIMENT WITH HUMAN MUSCLE ACTIVATION PATTERNS

We conduct walking experiments to confirm that the robot is able to perform dynamic tasks by using the complicated muscles. To realize dynamic walking, we used human muscle activation patterns (EMG data) for driving the pneumatic muscles. The human muscle activation patterns can be utilized in driving musculoskeletal robots because the structures are close to those of humans. Since pneumatic muscles can hold a given power by closing the valves, we decided how to drive the muscles by trial-and-error (Fig. 4). Fig. 5 shows the experimental sequence of the walking experiment. We realized a few steps without feedback and confirmed that the robot had enough power to perform dynamic walking. However, a stable periodic gait could not be achieved.

4. CONCLUSIONS AND FUTURE WORKS

In this study, we presented the musculoskeletal humanoid "Pneumat-BS" driven by pneumatic artificial

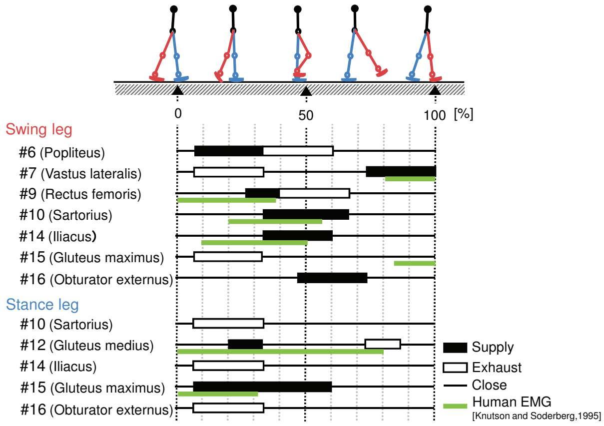

Fig. 4 Muscle actuation patterns with EMG (using [4]).

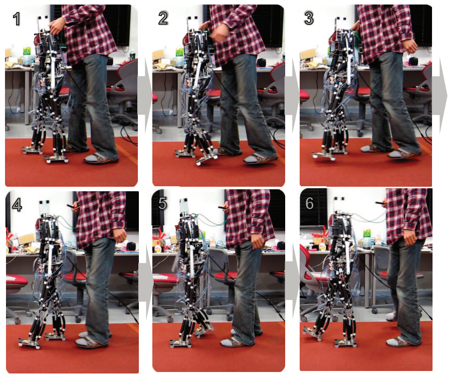

Fig. 5 Experimental sequence of walking experiment.

muscles, and we introduced that method to make muscle activation patterns for musculoskeletal humanoid using human EMG data and results of walking experiments. For future work, we have to develop a control method for the musculoskeletal robot and realize stable behaviors.

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