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Evaluation of weight bearing reduction system driven by rubberless artificial muscle

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Abstract. In this paper, we describe the evaluation of a weight bearing reduction system driven by a rubberless artificial muscle. This weight bearing reduction system lifts walker's trunk with rubberless artificial muscle and reduces the load on the lower limbs. A force feedback control system is applied to the rubberless artificial muscle to control force and displacement according to movement of a waist of the walker. The control performance of this force feedback system was confirmed through basic experiment. And we confirmed that the target force can be realized while adjusting the contraction displacement against increase or decrease of the load. Furthermore, we confirmed that this control system contributes reducing the load on the lower limbs during walking through the measurement experiment of the floor reaction force.

Keywords: Pneumatics, Artificial muscle, Weight bearing, Walking support, Force control

INTRODUCTION

Recently, aging of society is progressing rapidly in many countries. Simultaneously, interest in maintaining the health of elderly people is rising. Walking, an effective means of maintaining a healthy life [1], contributes not only to muscle power necessary to walk but also as motivation to do many things in daily life. By walking, elderly people incorporate various physical functions into their life. Subsequently, they go out and join the community, interacting with others. A healthy life can be maintained through these activities.

However, some elderly people might hesitate to walk because of diseases affecting the knees and waist or because of muscle weakness. Some means of walking assistance is necessary for these elderly people. Conventionally, a walking stick or a walking cart is used for walking assistance. These tools serve the function of supporting some of the user's weight. These are simple in structure and easy to use. However, if such a device supports body weight during only part of the gait cycle, walking balance might be lost.

Therefore, these tools are insufficient for stable walking assistance. To improve these shortcomings, several walking support devices applying robot technology are proposed [2]–[4]. Hirata [2] and Higuchi [3] also proposed a walking support device. These devices support some weight of the walking person, reducing the load on the lower limbs.

However, reduction of lower limb loads by these proposed devices is indirect. It is necessary to have balance with human body. The load reduction effect is not regarded as extremely large. Nihei [4] also proposed a unique walking assist device that amplifies the propulsive force by walking. It can move farther by one walking cycle. This device amplifies the moving distance of a user who can walk. Therefore, it is difficult to say that it provides reduction of the load on the lower limbs.

In a rehabilitation system [5]–[7] such as that examined in Moseley's research [5] or LOCOMAT [7], body trunk lifting movement in the vertical direction is adopted to reduce the load on the lower limbs. Because this method lifts the trunk of the user, it can reduce weight bearing more directly, without risk of falling. It is considered that the trunk lifting movement is effective for rehabilitation and for walking support.

Given that background, we are developing a weight bearing reduction system driven by rubberless artificial muscle as a small type weight bearing reducing device that can be attached to a walking cart. Using rubberless artificial muscles and air compressibility, this weight bearing reduction system is intended to be compact, soft, and high-powered.

In this study, force feedback control is adopted for the rubberless artificial muscle to realize weight bearing reduction for a walking person along with vertical movement of the waist during walking. Furthermore, we confirm the system usability by measuring the floor reaction force during a walking experiment.

WEIGHT BEARING REDUCTION SYSTEM

Rubberless artificial muscle

The rubberless artificial muscle (RLAM) used in this system is presented in Fig. 1 [8]. The drive mechanism of the rubberless artificial muscle is the same as that of a McKibben artificial muscle: contraction force is generated by using pressurized air to expand the airbag, which is inserted in a mesh sleeve. The airbag has a laminated structure of a polyester fiber sheet and a polyethylene sheet, with maximum pressure resistance of 0.6 MPa [9]. The McKibben artificial muscle which includes the RLAM has contraction force that relies on contraction displacement. This characteristic must be considered for application of these artificial muscles to a mechanical system. The isometric contraction characteristic of this RLAM is depicted in Fig. 2. RLAM generates a contraction force of about 150 N with inner pressure of only 0.14 MPa when it contracts by 15%. When some RLAMs are used with a displacement amount of about 15% as the movable range, it is possible to output a body trunk lifting force for a weight bearing reduction movement.

FIGURE 1. Rubberless artificial muscle (RLAM)

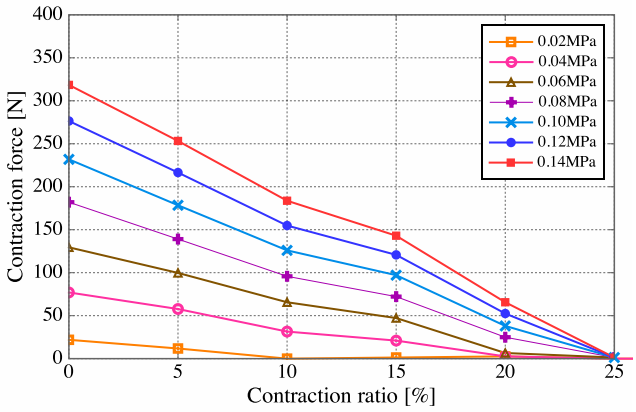

FIGURE 2. Isometric contraction characteristic of RLAM

Weight bearing reduction system

An outline sketch of the weight bearing reduction system driven by rubberless artificial muscle developed in this study is depicted in Fig. 3.

In this system, the rubberless artificial muscle lifts near the waist of the user and performs trunk suspension. In the future, the lifting mechanism of the waist including the rubberless artificial muscle will be placed near the sides of the user without passing over the head. Specific examination of that mechanism is a task for future investigation. In this study, as a basic function of the weight bearing reduction system driven by the rubberless artificial muscle, we confirm that it can reduce the user's body weight sufficiently by lifting his waist. Furthermore, we confirm the possibility of realizing an appropriate weight bearing reduction action, synchronizing it with vertical movement of the waist of the user.

In this study, we define maintenance of the target lifting force against weight bearing during walking motion constantly as an appropriate weight loading motion. In realizing this operation, the load on the lower limb is reduced by a constant amount, which is equivalent to reducing the user body weight in terms of the load on the lower limb. This system is expected to realize walking support through such an operation.

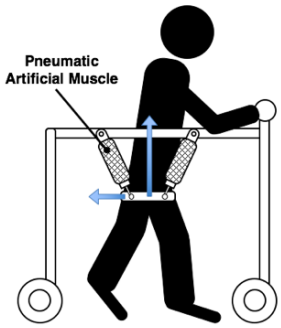

FIGURE 3. Conceptual diagram of weight bearing reduction system driven by rubberless artificial muscle

FORCE CONTROL OF THE RUBBERLESS ARTIFICIAL MUSCLE

The waist of the walking person is known to move vertically in the range of 25 mm during a human's natural walking [4]. Therefore, it is desirable to perform such an operation by which the target weight bearing reduction is constantly realized during vertical movement. For this reason, we apply a force feedback control depicted in Fig. 4, for which the target value is the amount of reducing the body weight to the RLAM. This feedback control system attenuates the high-frequency signal element of the force feedback signal through the low-pass filter.

The reason for this filtering of feedback signal is that it avoids the oscillating response caused by the high-frequency signal element acting as a signal noise to the feedback control.

The response tends to be delayed slightly by this filtering operation. However, because this system has a passive force characteristic related to the air compressibility, this system can be expected to support walking of the user softly. This study confirmed the response of the control system using the experimental system presented in Fig. 5. In this system, RLAM is fixed vertically. A load cell that measures the load of the RLAM is attached to

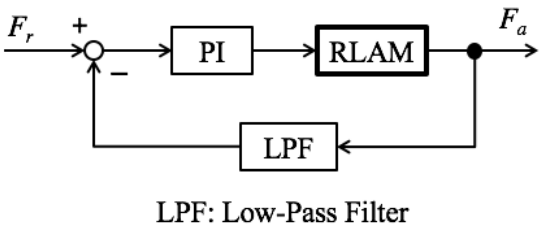

FIGURE 4. Block diagram of force control of RLAM

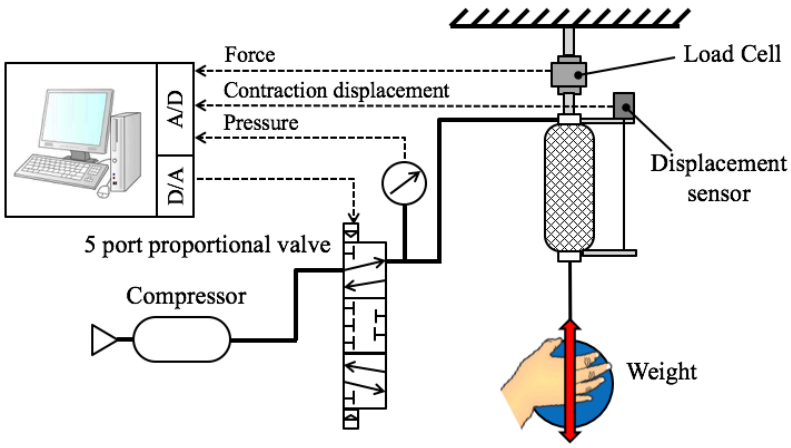

FIGURE 5. Schematics of RLAM force control experiment

the fixed end. In addition, a displacement sensor that measures the contractions of the RLAM is attached. An input pressure for the RLAM is controlled by a pressure feedback control system constructed using a five ports flow-rate proportional valve and pressure sensor.

Here, we set the target value of the weight bearing reducing force as 50 N. The weight of 50 N is hanging on the free end of the RLAM. We pulled or lifted this weight by hand. Then we examined the change of contraction displacement and contraction force at that time. One example of the obtained result in this experiment is depicted in Fig. 6. For this result, contraction displacement changes with changing of the load. We confirmed that the output force converges to the target value rapidly when changing of the load is stopped. In addition, the changing response of the contraction displacement is delayed with respect to changing of load. However, no oscillatory response is observed. Therefore, it is expected to realize appropriate movement for reduction of body weight bearing.

WEIGHT BEARING REDUCTION EXPERIMENT SYSTEM

In this experiment, the force feedback control is applied to the weight bearing reduction system. We confirm the possibility of realizing an appropriate movement of reduction of the weight bearing during actual walking motion. A schematic of the weight bearing reduction system and an actual experimental setup are portrayed respectively in Fig. 7 and Fig. 8. In this system, two RLAMs were arranged in a V shape on each side of the subject. Furthermore, these RLAMs and the waist of the subject are connected by an aluminum brace, and the body trunk was lifted. A load cell is attached to each RLAM, and the load by the body weight added to each RLAM is measured. An input pressure for the RLAM is controlled using a pressure feedback control system, which is the same as the system explained in the previous section. The same pressure is supplied to each of the four RLAMs from one control system. Therefore, four RLAMs are used in this experiment. However, we only evaluate the body weight bearing reduction in the vertical direction. The balance in the left-right direction during walking motion is not evaluated in this experiment.

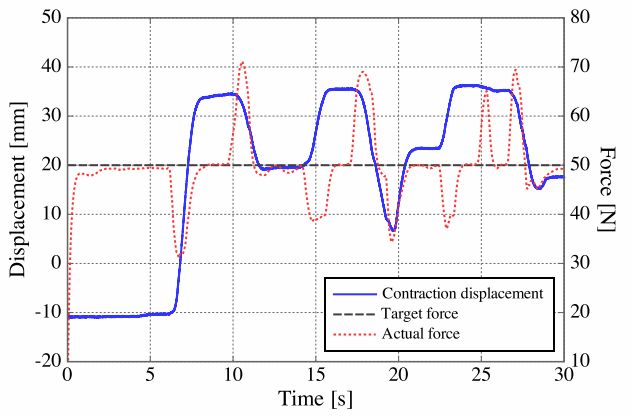

FIGURE 6. Experimental result of force control of RLAM

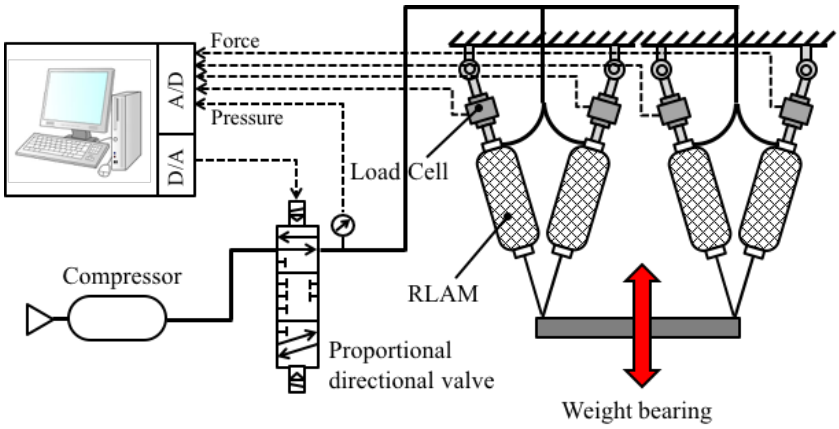

FIGURE 7. Schematics of the weight bearing reduction system

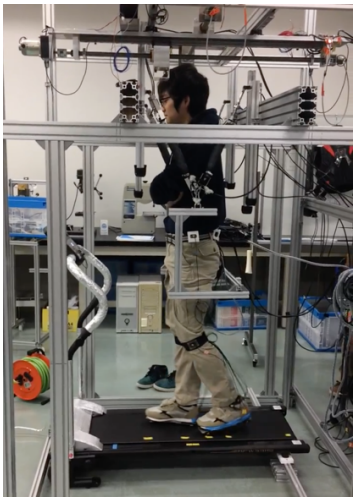

FIGURE 8. Experimental setup

a) Side view b) Bottom view

FIGURE 9. Force shoe developed for measuring floor reaction force

The reaction force on each leg during body weight bearing reduction experiment was measured using the force shoes we developed, as depicted in Fig. 9. We used two stainless steel cantilever beams and strain gauges for each shoe so that body weight imposed on the entire foot sole can be measured separately in the anterior and posterior of the sole. The subject walks on an electric treadmill. The waist position in the vertical direction at that time was measured using a position sensor (C5949; Hamamatsu Photonics KK). Using the system described above, we confirmed the effect of weight-bearing reduction during walking.

EXPERIMENTAL RESULT

The subject is a man in his 20s weighing 56 kg. For the walking experiment, we set the target delivered amount to 150 N. The obtained experimentally obtained results are presented in Fig. 10 and Fig. 11. In Fig. 10, the force

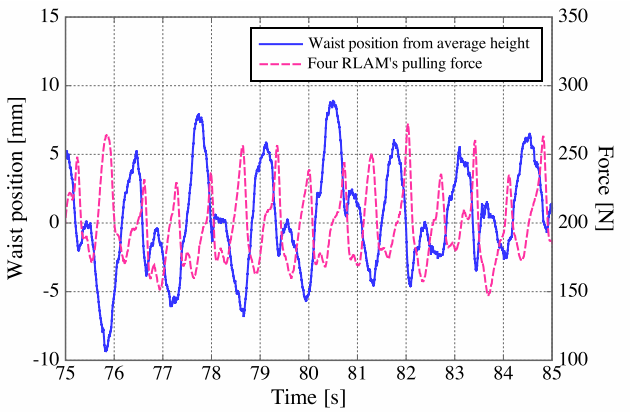

FIGURE 10. Waist position and pulling force of the walker's weight bearing reducing experiment

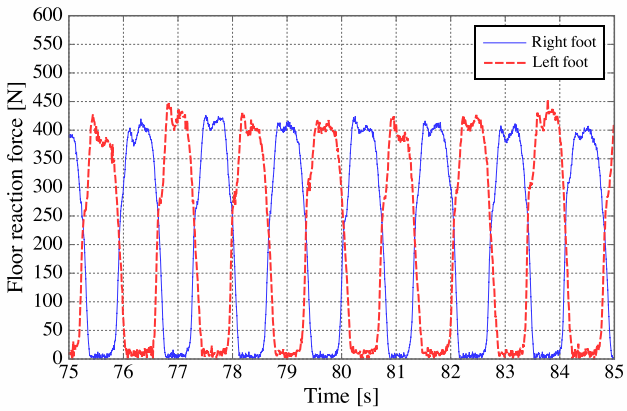

FIGURE 11. Floor reaction force of the walker's weight bearing reduction experiment

pulling RLAM changes in the range of about 50 N against vertical waist movement during walking. The tracking performance is not so good, but this is the result of applying a control system with a slightly slow response such as Fig. 5. Especially, although the waist position moves downward rapidly at 75.8 s, the weight bearing reducing force does not increase rapidly compared with other times. In addition, even if the position of the waist moves upward suddenly, such as 77.6 s or 80.5 s, the tendency of the weight bearing reducing force does not change.

These results demonstrate that the applied control system corresponds to the change of vertical motion of the waist. This system can realize the target walking support operation.

From the result shown in Fig. 11, the target weight bearing reducing force of 150 N is fundamentally realized because the maximum floor reaction force is 400 N. However, although the vertical movement of the waist changes greatly at 77.6 s and 80.5 s, as we confirmed in Fig. 10, the floor reaction force does not change greatly.

From this also, the applied force control is probably useful for the target weight loading operation.

CONCLUSION

This study was conducted to realize a body weight bearing reduction system driven by rubberless artificial muscle for a walking person. We evaluated the weight bearing action of this system experimentally. We applied force control to the rubberless artificial muscle and conducted the body weight bearing reduction movement during walking motion. Results confirmed that, although fluctuation occurred in the amount of weight bearing reduction with respect to the vertical motion of the waist, the target weight bearing reduction was realized from the side of the floor reaction force.

These results confirmed that the weight bearing reduction system proposed in this study is effective for reducing the load on lower limbs of walking elderly people.

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