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Pneumatic Walking Assistive System with a Soft Exoskeleton and a Follower Robot for Power Source

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In recent years, various power assistive devices with electric, pneumatic and hydraulic drive have been developed. The advantages of pneumatically-driven system such as light-weight, high power-weight ratio and direct drive are suitable for the devices. However, the method to provide air power source is a critical issue in pneumatically-driven devices. To solve the problem, we propose and develop a pneumatic walking assistive system with a soft exoskeleton and a follower robot carrying an air compressor. The exoskeleton is actuated by pneumatic artificial rubber muscles (PARMs) and walking intention is detected from the pressure change in the PARMs. The follower robot follows the wearer with a tether interface. The effectiveness of the system is confirmed with some experiments.

1 Introduction

In recent years, various power assistive devices have been developed[1]. They are electrically, pneumatically, or hydraulically-driven devices. Pneumatically-driven systems are light-weight and have high power-weight ratio, used as direct-driven system. These advantages are suitable for power assistive devices. A lightweight soft exosuit using pneumatic artificial rubber muscles (PARMs) for gait assistance has been developed[2].

However, providing air power source is a critical issue in pneumatically-driven devices. Connecting a device to a fixed air compressor with a pipeline will limit the walking range. Carrying an air compressor will burden the wearer.

To solve the problem, we propose and develop a pneumatic walking assistive system with a soft exoskeleton and a follower robot carrying an air compressor. The exoskeleton is actuated by PARMs. One of the challenges of exoskeletons are the detection of walking intention of the user while reducing the number of sensors. We have proposed a detection method using back-drivability of PARM [3] and in this paper it is also applied to the exoskeleton. We used a robot developed in [4][5], which is a vehicle with a tether following the user, to carry an air compressor. The effectiveness of the system is confirmed by experiments.

2 Pneumatic walking assistive system

In this paper, we propose a walking assistive system consisting of the pneumatically-driven light-weight soft assistive suit and the follower robot for carrying an air compressor and a pneumatic pressure control unit.

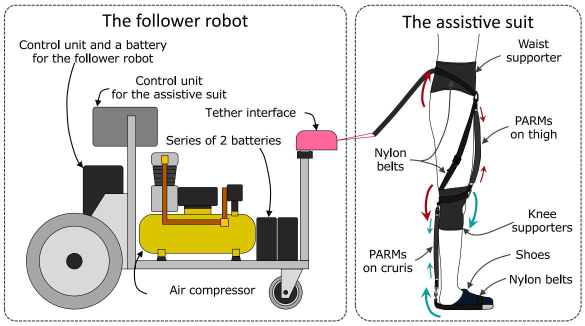

Fig. 1 The schematic of the pneumatic walking assistive system

3 Lightweight soft assistive suit

A wearable assistive suit which uses PARMs for actuators and harnesses of soft materials are developed.

Fig. 1 shows the schematic of the assistive suit. The assistive suit consists of PARMs, a waist supporter, knee supporters, and shoes. A wearer equips the supporters and put on the shoes with a nylon belt. PARMs are located anterior surface of thigh and facies posterior cruris. These PARMs assist the bi-articular muscles.

Each PARM are represented as **LT**, **LC**, **RT**, and **RC**, respectively. The prefix **L** and **R** are represented as the left leg and the right leg respectively. **T** and **C** are represented as the the thigh and the cruris respectively. PARMs on **LT** and **RT** provide torques for hip flexor and knee extensor. PARMs on **LC** and **RC** provide torques for ankle plantar flexor and knee flexor.

The assistive suit utilizes the back-drivability of PARMs to detect the walking intention of the user without additional sensors from the difference of internal pressure[3]. PARMs on **LC** and **RC** are used even as the sensors of intention detection. Fig. 2 shows the sequence of the assistive control. Initial pressures are applied to the PARMs to obtain an optimal detection sensitivity. When the wearer starts walking, the extension forces are increased to them and their internal pressures increase. The assistive suit detects the walking intention by monitoring the pressure derivative falling a predefined threshold.

When the wearer's gait phase changes from the stance phase to the swing phase, pressure derivative of PARMs on **LC** or **RC** falls below the pre-defined threshold ($-30\mathrm{kPa/s}$) and then the assistive suit starts to assist.

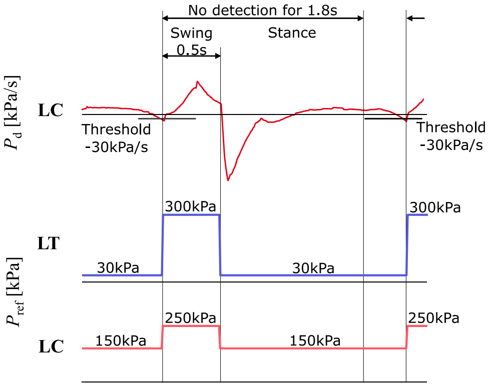

Fig. 2 The sequence of the assistive control

4 Follower robot equipped with an air compressor and control units

We utilize a follower robot[4][5] to carry an air compressor and an electric power source to control the assistive suit. This two-wheeled follower robot has a tether to connect the robot to a leader (the wearer of the assistie suit) and a winch to measure the length and orientation of the tether. Obtained tether length and angle are used to calculate the desired angular velocities for the left and right wheels which allow the cart robot to follow the wearer. The follower robot has a electrically-driven unit Joy Unit X (Yamaha Motor Co., Ltd.) and a Li-ion battery to drive the follower robot. The capacity of the Li-ion battery is DC25V/11.2Ah, which enables the follower robot $27\mathrm{km}$ distance drive.

We propose to mount an air compressor and control units, including four solenoid valves, four pressure sensors, two batteries, and a microcontroller, on the follower robot in order to expand the distance of the wearer's walking.

Fig. 1 shows the schematic of the proposed follower robot. The size, weight, power source, discharge rate, and tank volume of the air compressor is 480×190×420mm, 14.0kg, DC24V/24A, 116L/min and 8L, respectively. The size, weight and capacity of the battery is 181×76×167mm, 7kg and 12V/20Ah, respectively. The series of two batteries supply the power to the air compressor and solenoid valves and they can theoretically achieve the wearer's five-minutes walk with our assistive suit.

5 Experiments and results

5.1 Continuous operation experiment

We performed a continuous operation experiment for verifying the duration of the system that can assist the wearer's walking. The experiment is performed on the treadmill, with $2.0\mathrm{km/h}$ walking speed. The result shows that the 2600 sec walking is possible for the wearer.

5.2 Field test

We performed a field test for verifying the applicability of the proposed system on the practical use in the outdoor situation. The field test was performed on the outdoor situation, with $2.0\mathrm{km/h}$ walking speed. Fig. 3 shows the scene of the field test. The follower robot traces after the wearer with the assistive control even in the case that the wearer turns left or right. We verified the applicability of the proposed system on the practical use in the outdoor situation.

Fig. 3 The scene of the field test

6 Conclusion

In this paper, we proposed and prototyped a pneumatic walking assistive system consisting of an assistive suit with intention detection using back-driven PARMs and a follower robot to carry an air compressor.

The effectiveness is verified by two experiments as the method to expand the wearer's walking range; first, the continuous operation of $2600\mathrm{sec}$ walking with the proposed system is achieved, second, the field test demonstrated the applicability of the proposed system on the practical use in the outdoor situation.

Future works are minimizing air consumption and downsizing the follower robot.

References

[1] Tingfang Yan, Marco Cempini, Calogero Maria Oddo, Nicola Vitiello, "Review of assistive strategies in powered lower-limb orthoses and exoskeletons", *Robotics and Autonomous Systems*, Vol. 64, pp. 120-136, 2015.

[2] Michael Wehner, Brendan Quinlivan, Patrick M Aubin, Ernesto Martinez-Villalpando, Martin Baumann, Leia Stirling, Kenneth Holt, Roger Wood, Conor Walsh, "A lightweight soft exosuit for gait assistance", *Robotics and Automation (ICRA), 2013 IEEE International Conference on*, pp. 3362-3369, 2013.

[3] Takahiro Kanno, Daisuke Morisaki, Ryoken Miyazaki, Gen Endo, Kenji Kawashima, "A Walking Assistive Device with Intention Detection using Back-Driven Pneumatic Artificial Muscles", *Proc. of the 2015 IEEE 11th International Conference on Rehabilitation Robotics*, pp.565-570, 2015.

[4] Gen Endo, Ben Allan, Yu Iemura, Edwardo F Fukushima, Masatsugu Iribe, Toshio Takubo, Mineko Ohira, "Mobile follower robot as an assistive device for home oxygen therapy - evaluation of tether control algorithms", *ROBOMECH Journal 2015*, Vol. 2, Issue 1, pp. 1-9, 2015.

[5] Gen ENDO, Ben ALLAN, Takashi FUJIOKA, Takeshi TANAKA, Haruyo SHIMIZU, Fumihiko ONO, Hiroaki AZUMA, Tadasuke NAKANISHI, Masaya ISOBE, Development of a Delight Mobility Assistive Cart Robot for an Airport No.1: Development of first prototype, Annual Conference on Robotics Society of Japan, RSJ2015AC1K3-01, 2015 (in Japanese)