Proceedings of the 7th JFPS International
Symposium on Fluid Power, TOYAMA 2008
September 15-18, 2008

P2-35

DEVELOPMENT OF PNEUMATIC WALKING SUPPORT SHOES USING POTENTIAL ENERGY OF HUMAN

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ABSTRACT

Among the elderly person, most of their injuries are reported to be caused by falling down with stumbling. It is due to their shuffling walking style resulted from deterioration of their dorsiflexion muscle force along with aging. Walking plays an important role in their independent day life. In this study we aim at developing a wearable walking support equipment embedded into shoes for a purpose of fall prevention of elderly person. A commercial product of Ankle Foot Orthosis is introduced and newly developed wire type pneumatic actuator is equipped on to support dorsiflexion motion during swing period at walking motion actively. In generally, these kind of active supporting systems require power source. We propose a driving scheme with no use of electric power, but with only potential energy of the wearer. Required specifications for the equipment are derived and the validity of proposed walking support shoes is verified through some experiments.

KEYWORDS

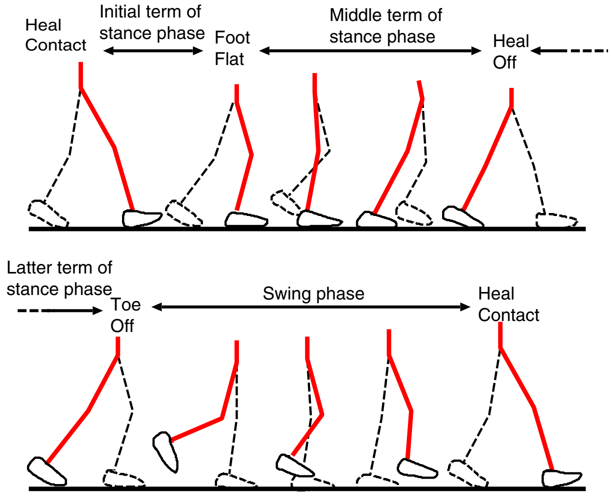
Walking support, Pneumatic driving system, Energy autonomous

INTRODUCTION

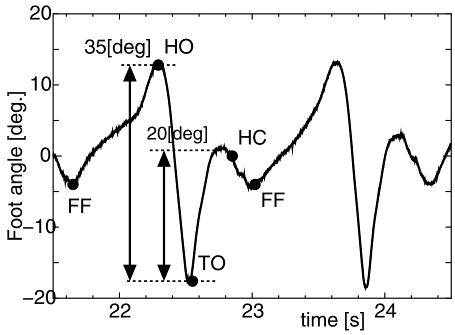
Japan is about to face a super aging society where aged person will occupy 35 % in the total population in 2050[1]. In spite that walking is indispensable for their independent day life, most of their injuries among aged person are reported to be caused by falling down with stumbling. It is supposed to be resulted from their shuffling walking style due to the deterioration of dorsiflexion muscle force along with aging. Once they fall down, they have higher possibility to break bones comparing to younger. Therefore it is significant to develop a walking support equipment to keep their standard QOL.

Some of these kind of equipment have been developed so far, such as, using ER actuator[2] as brake function by regulating viscosity for prevention of drop of foot, using a pneumatic passive element to hold variable stiffness function to support walking[3], using a pneumatic cylinder to support knee joint moment[4][5], using an exoskeletal robot to support gait motion[6][7]. However these equipments generally require energy like an electric power, which may bring problems of cost, total weight and reliability, etc. Therefore we develop a walking support shoes holding a driving mechanism using no electric power at all but just human potential energy.

In this paper, first of all, required specification for the equipment is adjusted and the overview of the equipment is described. After mentioning a driving mechanism of a proposed walking support shoes, the validity of the equipment is verified through some experiments.



(a) Walking aspect



(b) Foot angle in the walking motion

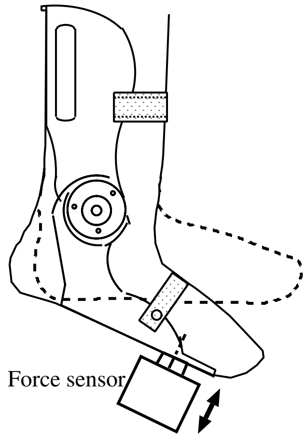
Figure 1: Foot angle trajectory

REQUIRED SPECIFICATION

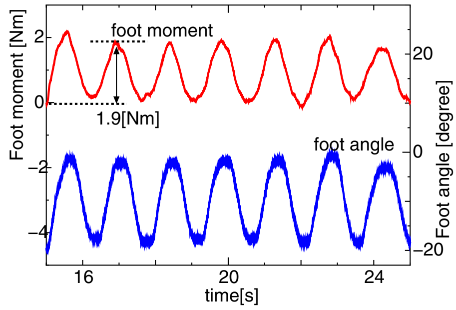
Fig.1(a) shows the walking aspect and (b) does the angle of ankle joint during walking. Angle of ankle joint at vertically standing situation is set as standard condition and dorsiflexion direction (direction of rising toe up) is set as positive.

From the state of whole surface of foot contacts with ground (Foot Flat : FF in the figure), the angle of ankle joint is increased along with forward tilting of a body and it reaches at maximum value when a heel leaves ground (Heel Off : HO). After that, the angle is rapidly decreased until toe leaves ground (Toe Off : TO) by the motion of kicking foot backward to obtain thrust forward and then dorsiflexion motion is implemented. In this time, the dorsiflexion angle of aged person is reported to be smaller. The purpose of this study is to raise this dorsiflexion angle by supporting with an equipment. It is confirmed from the figure that about 20 deg. is required for dorsiflexion motion.

In the next, the moment around an ankle joint to attain the 20 deg. of dorsiflexion angle is experimentally obtained. As shown in Fig.2(a), an ankle joint is forced to move about 20 deg. repeatedly from the angle of TO in Fig.1 through a force sensor. Figure (b) shows the calculated moment around ankle joint and foot angle, which indicate about 2.0 Nm is required to obtain a dorsiflexion angle.



(a) Measurement situation

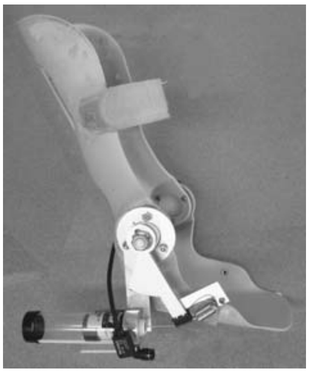


(b) required moment

Figure 2: Measurement foot moment

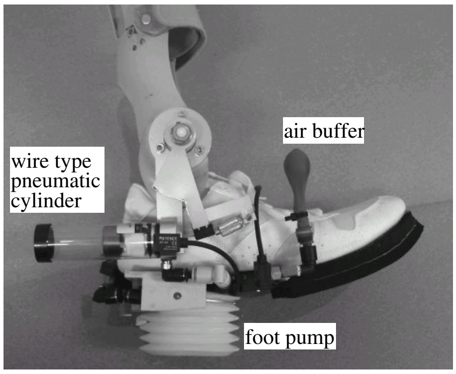
DEVELOPED WALKING SUPPORT SHOES

Fig.3 shows a developed walking support shoes. As shown in (a), newly developed wire type pneumatic cylinder is equipped via a moment arm on the commercial product of ankle foot orthosis (product name : Dream Brace). A foot pump is set under the heel as shown in (b) and an air buffer to accumulate compressed air temporally is also equipped. The air buffer is composed with several balloons, which contribute not only to lower the cost and total weight but to exhaust high pressure air into a cylinder owing to the restitution force due to the elastic property of balloons. In the figure (d), a pilot valve to change flow direction can be seen to be embedded at a middle of a shoe bottom. By utilizing pneumatic power not only

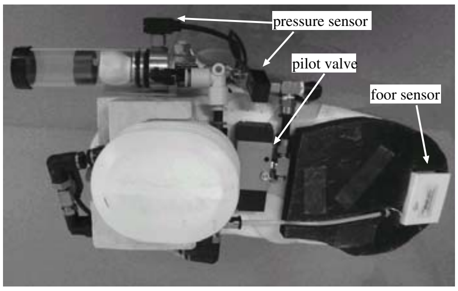


(a) ankle orthosis

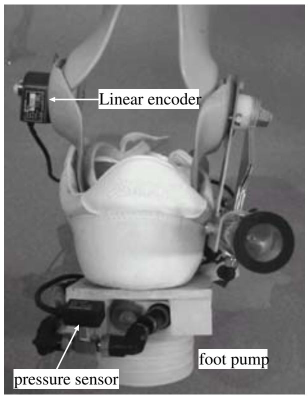
(b) shoes with foot pump



(c) Side view



(d) Sole view



(e) Back view

Figure 3: Walking support shoes

as an energy source but as a signal, we accomplish to develop a walking support shoes driven with no use of electrical power entirely. A foot sensor is equipped under the toe by connecting to a pilot valve with tube. The foot sensor is just a spring return type clip, which works as a mechanical switch to change flow direction by lowering pilot pressure.

Pneumatic cylinder (Airpel Co. 25mm diameter) is introduced as a driving actuator from a view point of its high power/weight ratio valid for wearable use. As shown in Fig.4, we improve the pneumatic cylinder mechanically so that it drives by wire instead of piston rod in order to be equipped at a narrow space. Concretely a balloon is inserted into a cylinder and a wire is connected to a piston through inner part of a balloon. The balloon acts as a seal to separate wire side from inner side of cylinder. Applying compressed air into the cylinder chamber, piston pull the tip of a moment arm for the heel side direction to generate dorsiflexion moment around ankle joint.

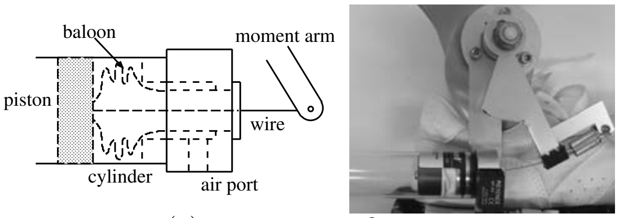
Table 1 shows the weight of each parts. Total weight is quite light of 860 g. Making further light and smaller is under the current investigation.

Table 1: mass of each part

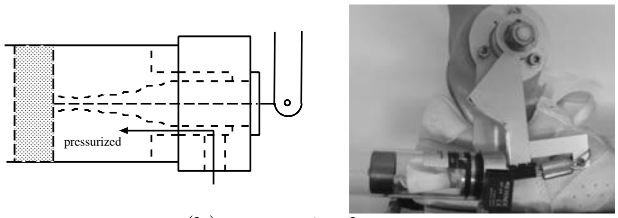
shoe itself(without bottom part)	135g	15.7 %
ankle foot orthosis	280g	32.6%
wire type pneumatic cylinder	80g	9.3%
bottom part of shoe (pump, pilot valve, foot sensor)	365g	42.4%
total	860g	100%

PNEUMATIC DRIVING CIRCUIT

Fig.5 shows a pneumatic driving circuit. A 5 port type pilot valve is introduced to switch flow direction. At the start state of contact period with walking, a wearer step on a foot pump with their weight. In this study, the compressed air at a foot pump is used as pilot pressure as well for ease. When pilot pressure overtakes certain value(about 60 kPa), compressed air at foot pump starts to flow into the air buffer and it is accumulated until the moment to support dorsiflexion motion. Pilot pressure port is also connected by a tube and its terminal is held by a mechanical



(a) un-pressurized state



(b) pressurized stater

Figure 4: Structure of wire actuator

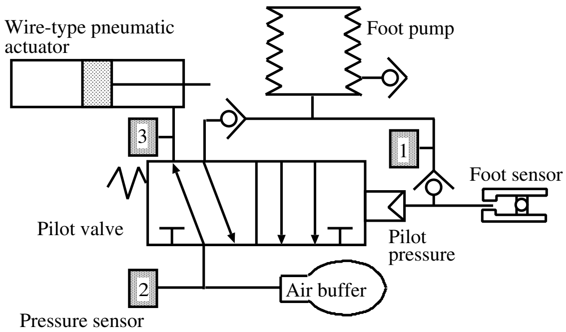
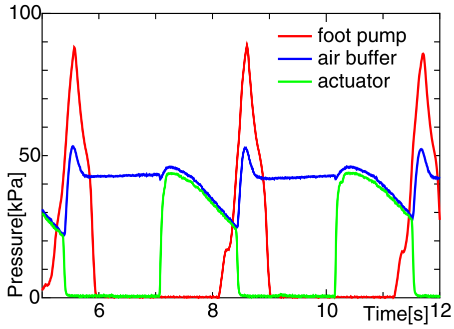


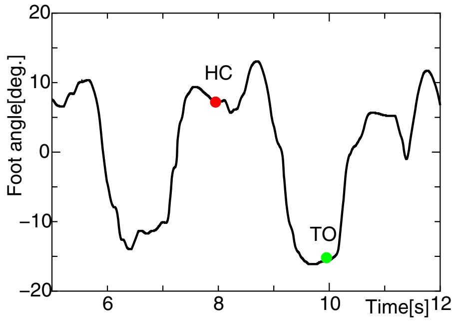
Figure 5: Pneumatic driving circuit

clip which is equipped under toe. At the end of contact period, a toe steps on the clip when toe separates from the ground, then a pilot pressure is opened to the atmosphere to let a pilot valve to switch. Consequently the accumulated air at air buffer starts to flow into the air cylinder to generate moment around ankle joint.

Fig.6 shows an aspect of response under the a series of motion mentioned above, where (a) and (b) indicate the pressure response of each part and angle of ankle joint respectively. In figure (a), pressure at foot pump (namely equal to the pilot pressure) shown with red line is rapidly increased as soon as the pump is stepped on at the time marked with HC (Heal Contact) in the figure (b). The blue line shows a pressure at an air buffer, which raises up when the pressure at pump takes over about 60 kPa. At the same time, the air at cylinder drawn by green line is opened for atmosphere to be 0. Consequently the ankle joint is not constrained by cylinder's force. This function is very important not to prevent a foot from implementing kick back motion. Then it is confirmed that the



(a) Pressure response



(b) Foot angle

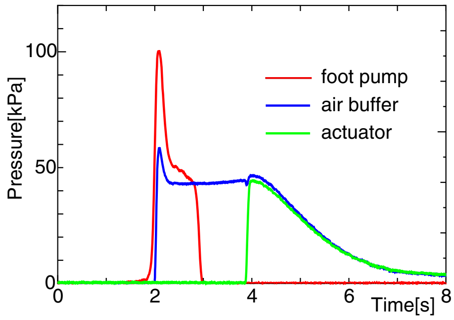
Figure 6: pressure response

pressure in a cylinder raises up when toe steps on the clip at the moment of separating from ground at the time marked TO in the figure (b).

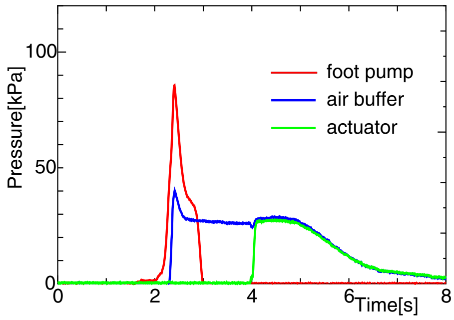
Fig.7 shows the effect of air buffer composed with balloons, where (a), (b) and (c) shows the case of using balloons of 5, 3 and 1, respectively. By putting over balloons, higher pressure can be applied to an air buffer and pneumatic cylinder owing to the increase of elastic property of rubber balloons. However a high pressure in a foot pump tends to prevent a wearer from a smooth stepping on a pump. The total number of leaves of balloons must be deiced under these trade-off between support efficiency and stepping feeling of wearer.

EXPERIMENTAL RESULTS

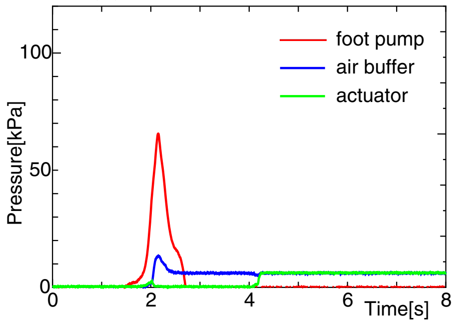
Fig.8 shows the effect of the equipment at simple dorsiflexion motion, where (a) and (b) correspond to the case with and without assist, respectively. EMG of dorsiflexion muscle is introduced to see the support effectiveness[8]. A subject implements a simple dorsiflexion motion repeatedly in order that the angle of ankle joint become the same in both case (a) and (b). In the case of (a), EMG shown with red line is confirmed to be declared comparing with that in figure (b) though the joint angle is almost the same among both cases, which shows the effectiveness of



(a) In case of 5 balloons



(b) In case of 3 balloons



(c) In case of 1 balloon

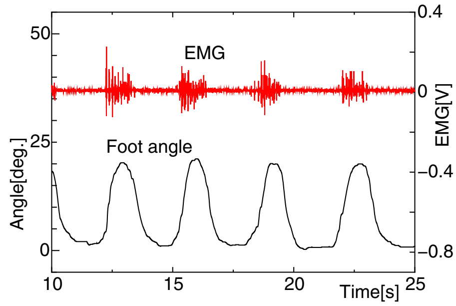
Figure 7: Effect of the number of balloon at air buffer

the equipment.

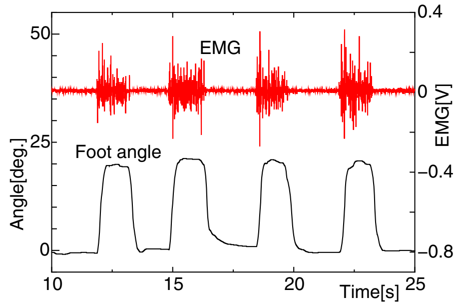
Fig.9 shows the same experimental results with Fig.8 except that a 0.5 kg of weight is put on the toe by supposing the wearer as aged person. This load equals to 1.0 Nm around ankle joint, which corresponds the half of required moment for dorsiflexion motion during walking. It is also confirmed smaller EMG in case (a) than that in (b).

Fig.10 shows the effectiveness during actual walking. A subject tries to walk in order the angle of ankle joint may be the same regardless of existence of assistance. In the case of actual walking, we can also confirm the deterioration of EMG by being supported with the equipment.

Fig.11 shows the same experimental results with that of Fig.10 except that 0.5 kg of payload is put on the toe like the situation of Fig.9. Even in the case



(a) With assist



(b) Without assist

Figure 8: Supporting the dorsiflexion

supposing the lowering of dorsiflexion muscle force, an EMG become smaller at dorsiflexion motion in spite the foot angles are kept with almost the same one in both case (a) and (b), which shows possibility of practical use.

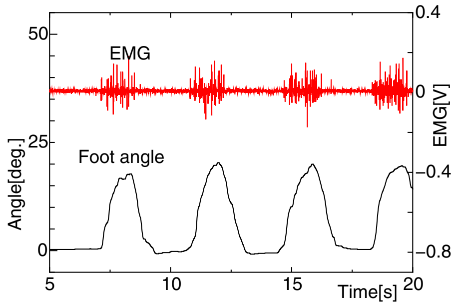
CONCLUSION

In this study, we developed a walking support shoes to prevent aged person from falling down with stumbling. The shoes has a feature to support a dorsiflexion motion using a pneumatic actuator during a swing period in a walking. We also proposed a driving mechanism with no use of electric power but with using only potential energy of wearer.

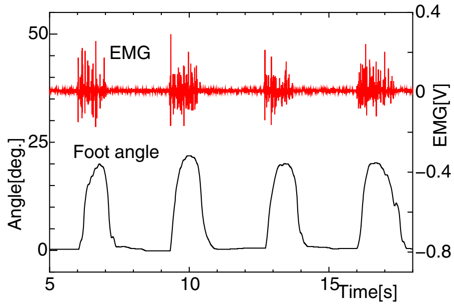
Concrete pneumatic driving mechanism from a view of flow direction using pilot valve was described.

The validity of the equipment were verified by comparing using EMG of dorsiflexion muscle force under the experiments concerning to a simple dorsiflexion motion and an actual walking one, which showed the effectiveness of the equipment in both cases.

Further improvement of supporting performances and of making smaller and light is under the current investigation.

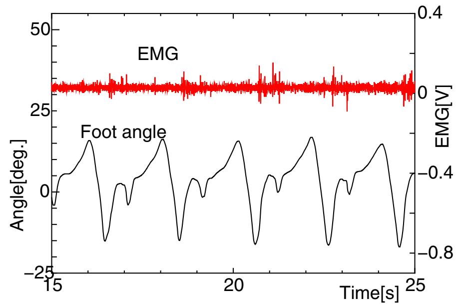


(a) With assist

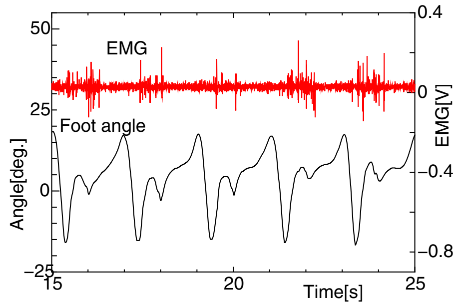


(b) Without assist

Figure 9: Support effect in simple dorsiflexion motion



(a) With assist



(b) Without assist

Figure 10: Support effect in walking with standard velocity

REFERENCES

1 Government of Japan,Annual Report on The Aging Society 2006, Chap.1 Status of population aging

2 Jason Nikitczuk, Brian Weinberg, Constantinos Mavroidis, Rehabilitative Knee Orthosis Driven by Electro-Rheological Fluid Based Actuators, Proc. of ICRA,pp.2294-2300, 2005

3 Hirai H, et.al, Development of an Ankle-foot Orthosis with a Pneumatic Passive Element, Proc. of ROMAN 2006, pp.220-226, 2006

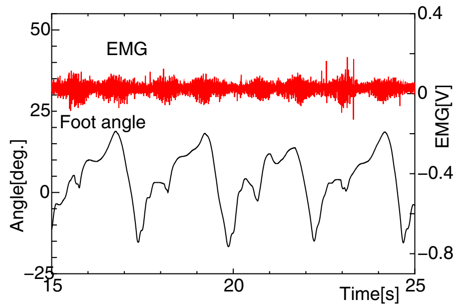
4 Kazuhiro Fujishiro, Tadayuki Ariumi, Osamu Oyama, Toshihiro Yoshimitsu, Development of Pneumatic Assist System for Human Walk, Proc. of SICE Annual Conference, 2003

5 G. Belforte, L.Gastaldi, M. Sorli, Pneumatic Active Gait Orthosis, Mechatronics 11, pp.301-323, 2001

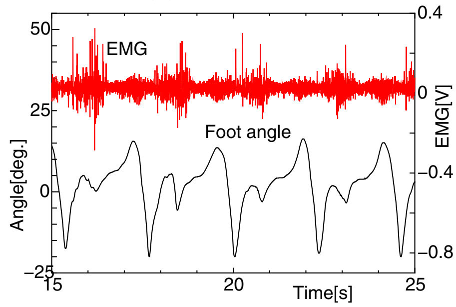
6 S. Lee, Y. Sankai, Virtual Impedance Adjustment in Unconstrained Motion for an Exoskeletal Robot Assisting the Lower Limb, Advanced Robotics, Vol.19, No.7, pp.773-795, 2005

7 J.Hidler, N.Neckel, Inverse-Dynamics Based Assessment of Gait Using a Robotic Orthosis, Proc. of the 28th IEEE EMBS Annual International Conference, pp.185-188, 2006

8 Elain N. Marieb, Essentials of Human Anatomy & Physiology, Igakusyoin, 2000



(a) With assist



(b) Without assist

Figure 11: Support effect in walking with payload