Design of Self-Contained Biped Walker with Pneumatic Actuators

Takashi TAKUMA[1], Seigo NAKAJIMA[1], Koh HOSODA[1,2], Minoru ASADA [1,2]

1 Dept. of Adaptive Machine Systems, Graduate School of Engineering,
2 HANDAI Frontier Research Center,
Osaka University
Yamadaoka2-1, Suita, Osaka, 565-0871,Japan
takuma@er.ams.eng.osaka-u.ac.jp
nakajima@mit.eng.osaka-u.ac.jp
{hosoda, asada}@ams.eng.osaka-u.ac.jp

Abstract: A McKibben artificial muscle has suitable properties for realizing walking and running biped robots such as light weight, springy nature, and efficiency. Since controlling McKibben muscles is difficult because of their nonlinearity, we have to design robot dynamic parameters carefully. If the parameters are designed properly, the walking controller can be simple. In this paper, we describe a developed walking biped robot utilizing McKibben muscles and study on the influence of dynamic parameters on walking behaviors.

Keywords: pneumatic actuator, McKibben artificial muscle, self-contained 2D biped walker, robot design

1. Introduction

Recent progress of humanoid robots have been attracting many people for their performances of human like behaviors. Almost all of the existing humanoids are actuated by electric motors. However, the torque provided by the motors is not enough to realize dynamic behaviors such as hopping and running. Kajita et al. investigated a running motion of a humanoid robot, but the result expected unrealizable power for the motors[2)].

An artificial McKibben muscle is one of the candidates for actuating walking and running bipeds because of its light weight, springy nature, and efficiency. Controlling the muscles is, however, very difficult because of their nonlinearity. In these twenty years, several articles have been devoted to derive dynamic equations of motion of robots with pneumatic actuators and to design optimal controllers based on the equations[3)4)]. However, the performance of the controller is not enough because nonlinearity of actuators is too complicated to be modeled as equations. Ham et al. used fast open-close valves to improve the performance of PD controller without any explicit dynamic models[5)]. However, the trajectory to follow desired one will be oscillated when the gains of PD controller increase because a behavior of the joint tends to be sensitive with nonlinearity of the actuator when the controller has large gains. Therefore the trajectory based controller is not suitable for the robot with the actuators.

Wisse et al. produced a biped robot with the actuator. They adjusted periods to open air valves to supply air into the actuators to let the robot walk[1)]. In order to realize walking by such a simple operation of the valves, we have to design the dynamic parameters of the robot carefully. In almost all conventional methods, kinetic design of the robot has been focused on because the robot can be controlled precisely even if the design of the dynamic parameters are not proper to walk. The robot with the pneumatic actuators, however, can not be controlled precisely and then it is important to design the dynamic parameters of the robot.

In this paper, we study on the influence of robot parameters on walking behaviors. It is important to adjust not only dynamic parameter but control parameter. We develop a self-contained biped walker with McKibben actuators. The robot has 3 joints and each joint are rotated by two actuators arranged in antagonistic pair. We change two types of the parameters : (i) control parameter : the waiting period to swing the leg and (ii) dynamic parameter : the position of the center of the gravity.

In section 2, we introduce the developed biped walker with McKibben muscles. In section 3, the experiment for the locomotion is explained, and then the conclusion in section 4.

2. Development of Self-contained Biped Robot

In this study, a McKibben artificial muscle, which is a kind of pneumatic actuator shown in fig.1, is used to actuate a robot. The McKibben muscle contains two principle components. It has inner inflatable bladder made of silicon and exterior braided shell made of nylon. The muscle expands radially and contracts axially when the air is supplyed into the inner tube shown in fig.1 upper, and it generates pulling force along the longitudinal axis. The actuator is extended when the air is exhausted froum it shown in fig.1 bottom. While the actuator is so light that it is about 20[g] in weight, it has complex dynamics due to the hysteresis or friction between the exterior net and inner tube. The actuator models have been proposed in some research[6)7)8)], and it is known that the pulling force is proportional to the inner pressure and to second order polynomial about the length of the actuator. We use the actuator made by HITACHI Medical Corporation[9)]. It is about 200[mm] in length and 20[mm] in radius when it contracts, and it generates the force about 800[N] when a pressure in inner tube is about 0.7[MPa].

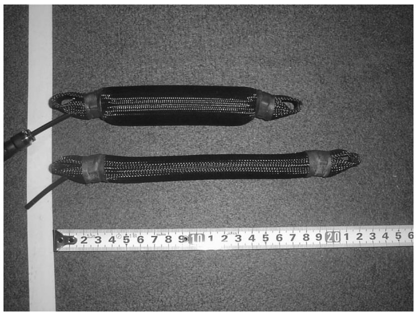

Figure 1: A McKibben type actuator. When the air is supplied into inner tube, it is shrunk (upper), and extend when the air is exhausted (bottom).

A brief illustration of biped robot we develop with the pneumatic actuator is shown in fig.2. It has three joints : at both knees and a hip. Each joint is rotated by two pneumatic actuators which are arranged by an antagonistic pair like human muscles.

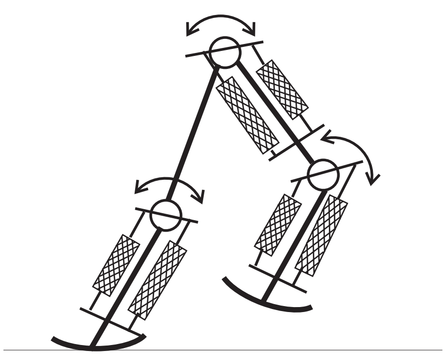

Figure 2: A brief picture of the produced robot. It has three joints : both knees and hip, and each joint is rotated by two pneumatic actuators which are arranged by antagonistic pair like human muscles.

Fig.3 shows a overview of the system to rotate one joint. The air supply and exhaust valves are attached on the actuator, and the actuator is contracted when supply valve is open and it is extended when exhaust valve is open. The PC operates air valves via D/A converter, and it reads sensory informations about a pressure in the actuator and an angle of the joint vi A/D converter. In fig.3, the joint is rotated toward counter clock wise when the actuator 1 is contracted while the actuator 2 is extended, and vice versa.

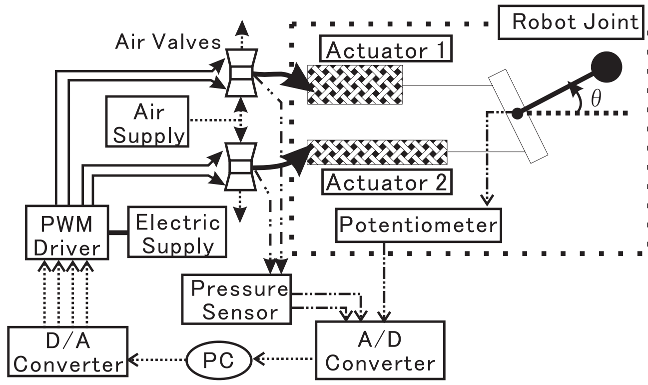

Figure 3: Whole overview of the system

Fig.4 shows a basic structure of the robot with pneumatic actuators. The frame is made of aluminum and the six actuators are arranged to rotate joints. The robot has four legs. Outer and inner legs are moves together respectively, then the robot walks in the sagittal plane.

Fig.5 shows the robot for self-contained biped walker. The robot has (a) a micro computer(H8/8067) as a D/A and a A/D converters, (b) two CO_2 bottles as the air supply sources, and (c) six electromagnetic valves for the air supply/exhaust. Though the PC temporarily calculates to operate valves, the micro computer also deals the planning in the future. A shape of the foot (d) is arc at which a radius is 125[mm] and a length is 160[mm]. It has an ON/OFF switch on the sole, and the switch detects the collision of the ground to generate the gait described in the next section. Table 1 shows weight and size of the links of the robot. The height, width and weight of the robot is 750[mm], 350[mm] and 5[kg] respectively.

Table 1: size and weight of the 2D biped robot

Link	length[m]	weight[kg]
Outer upper	0.3	2.18
Outer bottom	0.35	0.46
Inner upper	0.3	2.12
Inner bottom	0.35	0.5

3. Walking experiment

3.1 Gait strategy

The pneumatic actuator is light and it is suitable one for the robot to hop or run. However it is difficult to control because the actuator has complex non-linear dynamics, therefore the trajectory-based control method such as ZMP criteria can not be used. Thus in this study, as Wisse et al. did[1)], the gait is generated by regulating the duration to open/close the air valve. Fig.6 shows a illustration of the gait. The valves are operated such that

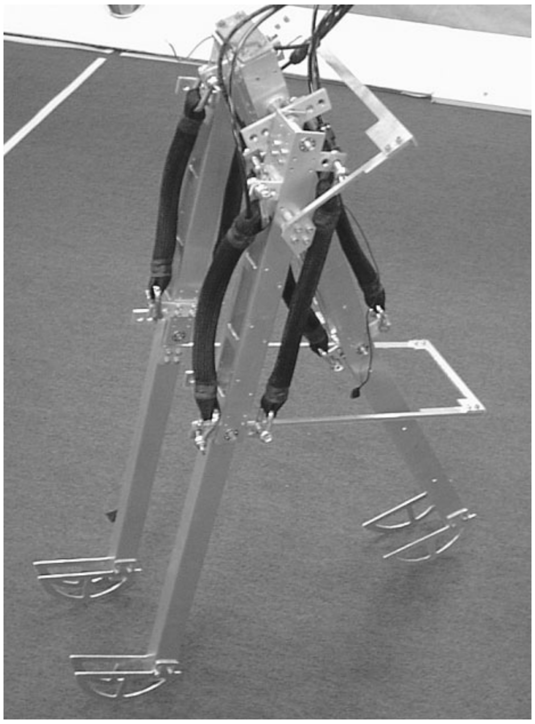

Figure 4: A basic structure of the robot with pneumatic actuators

(a) all valves are not operated for t[msec] from a heel strike. After t[msec], the valves are opened/closed to supply/exhaust air so that the hip joint rotates to swing the leg and that the knee joint rotates to bend the knee.

(b) The swing leg is kept bending the knee for 200[msec] and then the valves are opened/closed to rotate knee joint to stretch the knee. The duration 200[msec] is empirically determined to avoid the collision of the foot on the ground.

(c) All valves are not operated to keep the posture till the swinging foot touches the ground. After the heel strike, the swinging leg becomes support leg, and return to the operation (a).

In the operation (a) and (c), the collision of the ground is detected by the switch on the sole shown in fig.5 (d).

3.2 Experiment of the locomotion

The gait is generated by the simple valve on/off pattern mentioned above, but it is not sufficient to walk because a dynamics of the robot is not considered. In the trial, the robot was indeed tumbled due to the swing foot hitting the ground. If the robot has electric motors, the trajectory to avoid the collision of the ground can be planned. However the robot developed can not follow the trajectory precisely due to the characteristics of the actuator mentioned above. Then we take an another approach that the robot is designed so well that the robot can walk with a simple controller. In order to

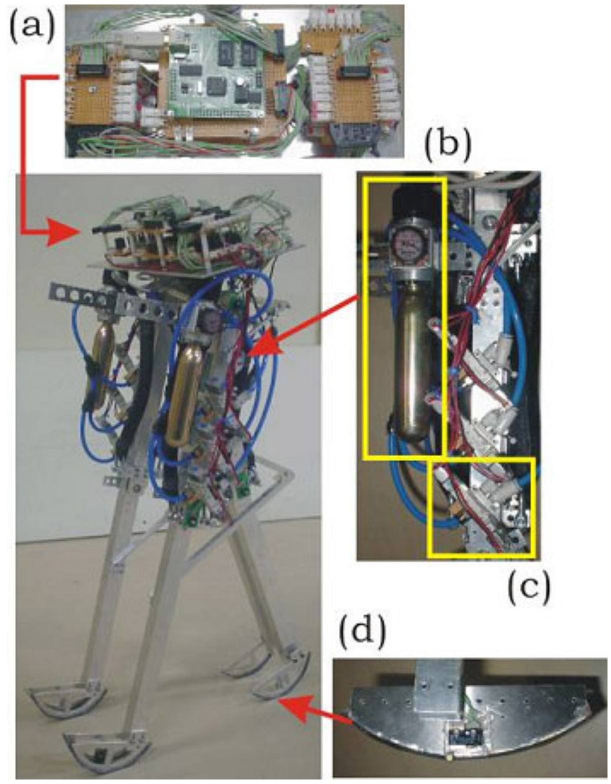

Figure 5: The self-contained biped walker. It has (a)a micro computer H8, (b)two CO_2 bottles as air supply, (c)on/off valves, and (d)a switch attached on the foot sole

realize the approach, we observe the influence of such two parameters on the locomotion as:

(i) a duration to open/close the valves

The robot developed has 3 degree of freedoms. The knee joint of the support leg does not rotate during the step, then two joints, the hip joint and the knee joint of the swing leg, are rotated. A stride of the step depends on the duration to rotate the hip joint, then the gait is changed severely if the period to rotate the joint is changed. The other joint, the knee should be bend as possible as it can to avoid the collision of the ground. Then in this study,

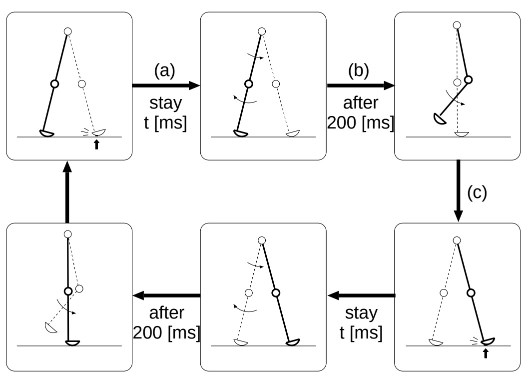

Figure 6: A gait pattern

the duration from the heel strike to the begining of swinging the leg, t is changed.

(ii) a robot design

The robot we developed walks on a level floor based on a passive dynamic walking e.g. the robot walks using its gravity and it need not excess consumption of the energy. One of the key element of passive dynamic walk is a center of the gravity (COG) of the robot. Thus we operate the position of the COG. In order to operate COG, we change the position of the CO_2 bottles. The bottles are 1[kg] in weight while whole weight of the robot is 5[kg], and it is expected that a variation of the position of the bottles is enough to change the position of the COG. Thus the length from an axis of the hip joint to the position of the bottle, l shown in fig.7, is changed. If a suitable position of the bottles is set, it is expected that the controller to walk can be simple by changing the duration t.

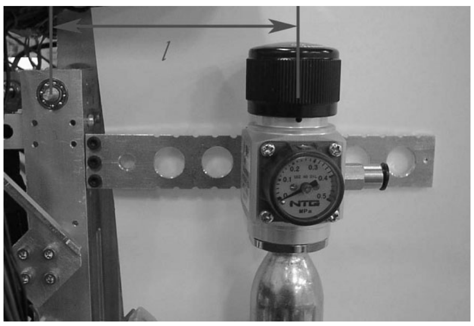

Figure 7: A distance l from the axis to the bottle position

In this paper, a mean and variety of the total steps at each set of t and l is observed. t is changed 0[msec]$\leq t \leq$ 88[msec] at every 4[msec], and l is done 66[msec]$\leq l \leq$86[mm] at every 8[mm]. In each set of the duration and the position, the numbers of the walking steps are observed for 5 times. The results are shown in fig.9. Fig.9 (a) shows the mean and variation of the steps when l is fixed at l = 74[mm] and t is changed, and (b) shows ones when t is fixed at t = 16[msec] and l is changed. (c) shows mean steps when t and l are changed. From the result (a), it is declared that the robot can walk by adjusting the moment to start swinging the leg, and from (b), it is declared that the robot can walk only by changing the duration t if the position of the COG — the robot design — is set appropriately. From (c), it is declared that the robot can walk more long distance by adjusting l and t. The picture that robot walks for 11 steps are shown in fig8. In addition, the robot can go up and down the 2^{circ} slope by adjusting the duration and position t and l. When the robot goes up, the position of the bottle is far ahead, and when the robot goes down, the position of the bottle is far backward, and the time t is adjusted in each case.

Figure 8: A sequential picture of 11 steps on the level floor

4. Conclusion

This paper indicates the influence of the dynamic/control parameters on the locomotion of the robot with pneumatic actuator, and it introduces the mechanism of the robot we developed. The McKibben muscle is light and it is expected to actuate the robot to generate more dynamic behavior, but it is difficult to control because of the nonlinearity of the actuator.

We expect that the robot can walk if the dynamics of the robot is designed properly, then we observe the influence of the dynamic/control parameters such as a duration to swing the leg and the position of the COG respectively. In result, the locomotion is influenced by these two parameters, and then the robot can walk with simple sequences of the operation of the air valve when the parameters are set properly.

Though the robot can walk on flat plane or shallow slope by setting the parameters proper values, it can not walk on the ground where an incline of the slope is changed continuously. One of the solution will be that the design of the robot is changed dynamically in response to the state of the ground, and it is future work.

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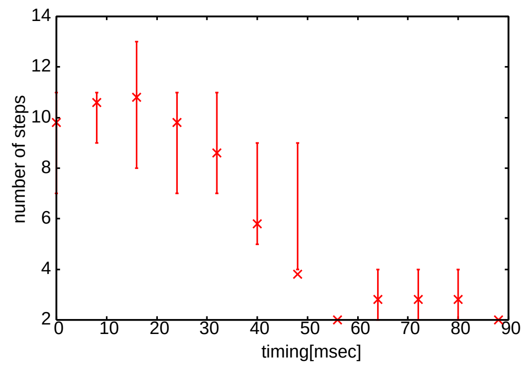
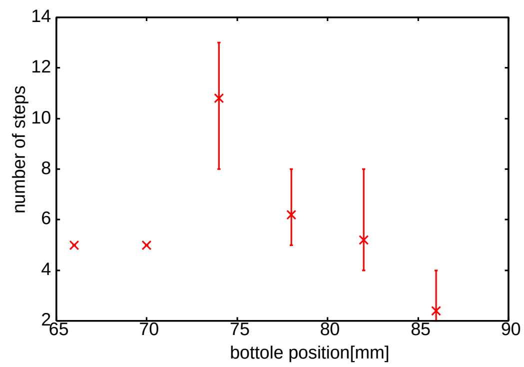
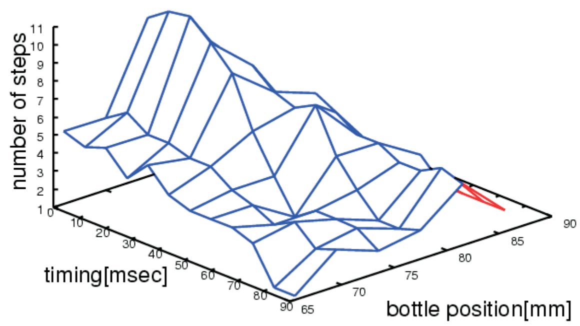


(a) average number of the steps vs. t when $l = 74$[mm]



(b) average number of the steps vs. l when $t = 16$[msec]



(c) average number of the steps vs. t and l

Figure 9: The influence of timing t and position l on walking. (a) An average number of steps with error versus t when $l = 74$[mm], (b) the one versus l when $t = 16$[msec], and (c) an average number of the step versus t and l.