Development of 3D Quadruped Robot with Animal-like Trunk and Leg Mechanisms

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Abstract: One major challenge in the development of quadruped robots is achieving animal-like energy efficient locomotion at low computational cost. In this regard, joint viscoelasticity such as that found in animals has been attracting considerable attention. In the present paper, based on animal body designs, we introduce a quadruped robot that has (i) a trunk mechanism with multiple passive joints with tunable viscoelasticity and (ii) legs driven by viscoelastic pneumatic actuators. We carry out an experiment to determine the effect of the viscoelasticity of the truck joints on dynamic locomotion of the robot.

Keywords: trunk structure, quadruped locomotion, joint viscoelasticity

1. INTRODUCTION

One highly promising approach to achieving energy efficient dynamic locomotion at low computational cost is adopting animal body designs, especially passive joint mechanisms. Some research has already been reported on viscoelastic joints [1]. In the present study we focus on a robot trunk design that has redundant joints, similar to an animal ’ s spine. The joints have tunable viscoelasticity, similar to living muscles. We also consider a leg structure driven by antagonistic muscles. We have previously reported that such a trunk mechanism facilitated locomotion constrained to a 2D plane with simple leg actuation [2]. In the present paper, we describe the results of an experiment carried out on a 3D quadruped robot that has a trunk with redundant viscoelastic joints and legs driven by pneumatic actuators. The results demonstrate that the robot achieves dynamic trotting locomotion with a simple gait pattern. We determine the appropriate combination of joint viscoelasticity and walking cycle that provides the most energy efficient locomotion.

2. DEVELOPED QUADRUPED ROBOT

Figure 1 shows the developed quadruped robot. It is 0.35 m high, 0.32 m wide, 0.53 m long, and weighs 4.8 kg. The robot has an animal-like trunk structure that has redundant joints with tunable viscoelasticity. It also has four legs driven by antagonistic pneumatic actuators. The actuators are operated by simple ON/OFF air valves. The leg joints are viscoelastic, and passively bend when the robot is placed on the ground.

Figure 2(a) shows the design of the trunk. We adopt an animal-like spinal structure with redundant joints. The trunk has vertebrae made of chemical wood, as shown in Figure 2(b) and intervertebral discs made of rubber, as shown in Figure 2(c). Both the vertebrae and the intervertebral discs have circular cross sections so that the trunk can bend and stretch in arbitrary directions. The vertebrae and intervertebral discs have holes, through which non-extensible wires are passed. One end of each wire is fixed to the head of the trunk, while the other is wound by a winch. The tensile force exerted on the wires, which corresponds to the compressive force on the trunk, can then be varied by rotating the winch. A force sensor is attached to the head of the trunk as shown in Figure 2(a) to measure the tensile force on the wires. Because the tensile force is correlated to the viscoelasticity of the trunk, we use this force as the viscoelasticity parameter.

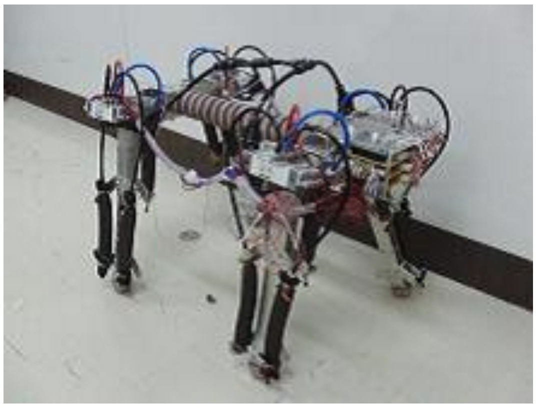


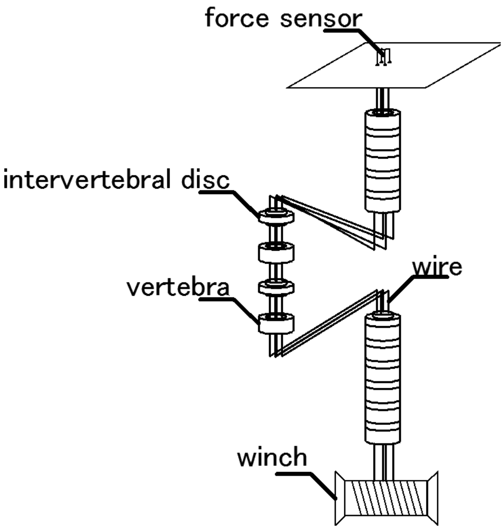
Fig. 1 Developed quadruped robot

Figure 3 shows the configuration of the pneumatic actuators to drive the legs. In this study, we use McKibben pneumatic actuators and, as shown in the figure, each leg has two joints and four actuators. Joint $i (i = 1, 2, 3, 4)$ is driven by two actuators ei and fi.

3. EXPERIMENT

3.1 Setup

In the experiment, the trotting pattern shown in Figure 4(a) was adopted. In order to investigate the most appropriate trunk viscoelasticity for different walking cycles, we systematically recorded the walking velocity for walking cycles of 0.50, 0.68, 0.83, and 1.00 s, and tensile forces of 291, 318, 373.0, 403.7, and 449.4 N. The walking velocities with the trunk made rigid by immobilizing its joints using a lightweight metal plate were also



(a) trunk design

(b) vertebra

(c) intervertebral disc

Fig. 2 Trunk design including redundant joints and tunable viscoelasticity

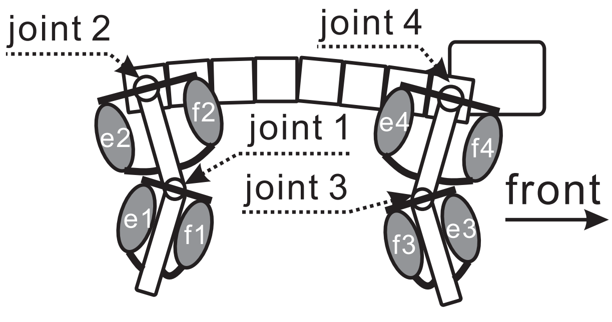
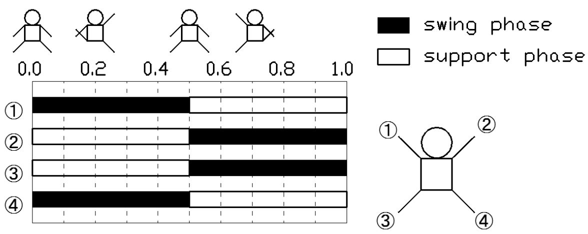
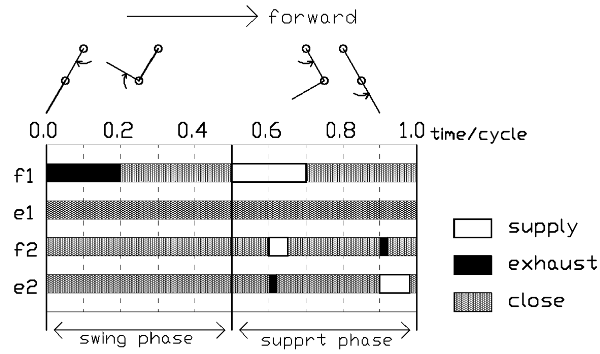


Fig. 3 muscle configuration



(a) swing / support phase chart for trotting



(b) supply / exhaust timing chart

Fig. 4 leg operation for trotting

recorded. The timing chart for each pair of air valves (supply / exhaust / close) is shown in Figure 4(b). Since the trunk has passive viscoelastic joints, it is not necessary to plan the trajectory of each joint, so that the robot walks at very low computational cost.

3.2 Results

Table 1 shows the experimental results. The values indicate the walking velocity (cm/s), and "*" means that the robot could not walk for a distance of 1 m within 120 s. The dark and light shading indicates the 1st and 2nd highest velocity for each walking cycle, respectively. These results lead to the following conclusions. First, the robot can achieve successful trotting locomotion by an appropriate choice of viscoelasticity for each walking cycle. Second, the robot cannot achieve locomotion when its trunk is a single rigid body. Finally, since the amount of energy expended (air consumption) was almost the same for each trial, velocity can be directly equated to energy efficiency. Therefore, Table 1 indicates that the robot can achieve energy efficient locomotion by tuning the viscoelasticity of the trunk structure depending on the walking cycle.

Table 1 Experimental results : average velocity for different walking cycles and tensile forces (unit : cm/s)

		walking cycle [s]			
		0.50	0.68	0.83	1.00
tensile force [N]	291.0	*	*	*	*
	318.0	*	*	*	3.16
	373.0	*	*	2.65	3.76
	403.7	*	*	4.73	3.37
	449.4	*	1.96	5.88	2.84
	rigid body	*	*	*	*

REFERENCES

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