The Effect of Morphology on the Spinal Engine Driven Locomotion in a Quadruped Robot

Qian Zhao, Hidenobu Sumioka, and Rolf Pfeifer

Artificial Intelligence Laboratory
Department of Informatics, University of Zurich
Andreasstrasse 15, CH-8050 Zurich, Switzerland
E-mail: (zhao, sumioka, pfeifer)@ifi.uzh.ch

Abstract: The biological hypothesis of spinal engine states that the locomotion is mainly achieved by the spine, while legs only serve as assistance. Inspired by this spinal engine hypothesis, a compliant, multi-DOF, biologically inspired spine has been developed and embedded into a quadruped robot without actuation on legs. The experimental results support this spinal engine hypothesis and reveal that this kind of robot can achieve rapid, stable, and even dynamical locomotion by appropriately tuning the spine's morphological parameters, e.g., rearranging the silicone blocks.

Keywords: Spinal engine, Locomotion, Quadruped robot

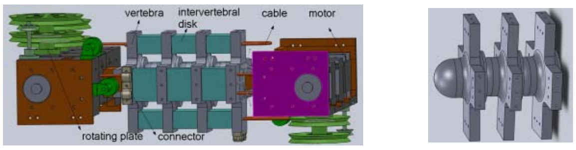
1. INTRODUCTION

Over the past decades, it has been widely accepted that locomotion is generally achieved by the coordination of the legs and the spine is only considered to be carried along in a more or less passive way [1]. This popular hypothesis has been accepted by most of robotics researchers as well as biologists. A considerable amount of research has been conducted on legged robots with little consideration on their spines [2]. However, Gracovetsky has proposed an alternative hypothesis with an emphasis on the spinal engine in human locomotion, i.e., locomotion is firstly achieved by the motion of the spine; the limbs came after, as an improvement but not a substitute [3]. Then, he extended this hypothesis to quadruped animals featuring flexion-extension spinal movement [4]. This implies that the spine is the key structure in locomotion. Recently, some robotics researchers came to realize the importance of the spine, but most of them still consider the spine as an assistant element to enhance the capability of locomotion [5], [6].

In this paper, we proposed a biologically inspired spine model and its application to a real quadruped robot to investigate its role in locomotion. Preliminary experimental results support the hypothesis of spinal engine and reveal that rapid and dynamical locomotion can be achieved only by actuating the biologically inspired tendon-driven actuated spine, without taking the actuation of the legs into account. More morphologies of the spine are explored and the results suggest that the locomotion behavior can be changed by tuning the morphology of the spine.

2. BIOLOGICALLY INSPIRED SPINE MODEL

Fig.1 (a) shows an artificial spine endowed with biological characteristics. It consists of cross-shaped rigid vertebrae made of ABS plastic, silicon blocks and cables driven by motors. The vertebrae are separated by the silicon blocks, which work as intervertebral discs. They are connected by a cable through themselves and the silicon blocks. The four driven cables are pulled respectively by four RC motors, which can control the stiffness and movement of the spine. In this design, multiple socket-ball joints (Fig.1 (b)) are taken to produce a more versatile posture and a wider motion space. The resulted spine can be bent in all directions within a certain predefined angle and form asymmetrical complex configuration by rearranging the silicone blocks in between.



(a) (b)

Fig. 1 The whole spine structure (a) and its socket-ball joints (b).

3. DESIGN OF THE QUADRUPED ROBOT

The developed artificial spine is embedded into a quadruped robot (29 cm wide, 23 or 25 cm long, 20 cm high and 1.1 kg). There are 3 linear springs in each stick-shaped leg to cushion shock from the ground. The legs are fixed to the body. The bottom of foot is glued with asymmetrical friction material to control the walking direction. Sine waves with tunable parameters are taken as control signals for 4 motors to generate the spinal movement.

4. EXPERIMENTAL RESULTS

To better understand the role of spine in locomotion and the correlation between its morphological property and locomotion behavior, a series of experiments were conducted under the condition of different spinal structures which differ in the shape and the stiffness distribution. During the experiments, several control parameter sets were tested for 5 trials and the best one was chosen. Fig.2 shows two robots equipped with symmetrical rectangle and rhombus shaped spines.

(a) (b)

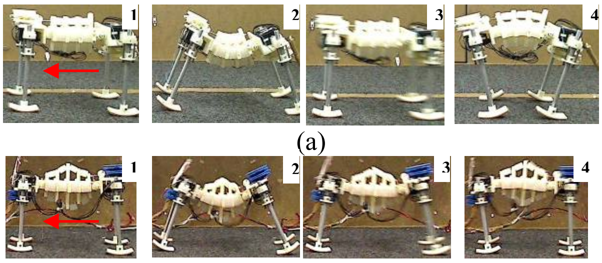
Fig.2 Robots equipped with rectangle (a) and rhombus (b) shaped tendon-driven actuated spine.

4.1 Moving forward

Table.1 shows that the robot is able to walk forward rapidly with stable and reproducible performance. We have also observed the shape of the spine does not affect much on its speed. Fig.3 exhibits the symmetrical, periodical flexion-extension spinal movements generating power to locomotion. However, its feet slide on the ground due to the lack of ground clearance.

Table. 1 Results of the moving forward performance

Symmetrical spine shape	Rectangle	Rhombus
Ave speed (cm/s)	14.5	11.7
Std speed	0.3	0.3



(a)

(b)

Fig.3 Sequential pictures of the robot's locomotion with the rectangle (a) and rhombus (b) shaped spine under the same control set. The red arrows represent the walking direction.

4. 2 Turning left/right

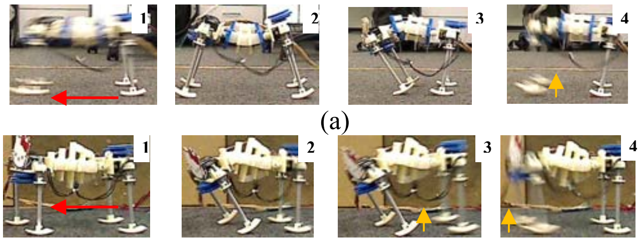
Table.2 shows the robot is able to turn right or left stably with the symmetrical rectangle shaped spine by introducing the lateral movement in addition to the flexion-extension movements. The speeds slightly differ due to the manufacture and assembly error.

Table. 2 Results of turning performance

Rectangle-shaped spine	Turing Right	Turing Left
Ave angular speed (°/s)	6.2	5.1
Std angular speed	1.0	0.5

4. 3 Dynamical movement

In this experiments, the asymmetrical spine morphologies are introduced where the silicones in the fore part of the spine were partially taken out in the above two morphologies. Fig.4 exhibits more dynamical lifting up movement based on these two new morphologies due to the asymmetrical arrangement of the silicone blocks. However, the rhombus shaped spine can lift up not only the fore legs, but the rear legs, which might be explained by the more asymmetrical stiffness distribution formed by this shape.



(a)

(b)

Fig.4 Sequential pictures of the robot's locomotion with the asymmetrical rectangle (a) and rhombus (b) shaped spine under the same control set. The yellow arrows represent the movement of lifting up.

5. CONCLUSIONS

A novel highly-compliant, multi-joint artificial spine inspired by biology has been developed and applied to a quadruped robot to test the biological hypothesis of spinal engine. Preliminary experimental results showed that the rapid and stable forward moving can be achieved when the silicon blocks are distributed symmetrically in the spine, whereas more dynamical movement can be observed by taking asymmetrical distribution of silicon blocks. This phenomenon has been observed in the cases of both the rectangle and rhombus morphologies, but the robot equipped with rhombus-shaped spine can lift up rear legs, which might be interpreted by its spine's ability to generate more complex asymmetrical configuration. The sensitive turning performance in the rectangle case has been observed to further support the spinal engine hypothesis.

All the results emphasized the concept of spinal engine and demonstrated the possibility for a robot to achieve different locomotion modes by appropriately tuning the morphological parameters of the spine without taking the actuation of the legs into account.

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