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P01

Why are cheetahs so powerful?
S-shaped flexion spine effect on cheetah galloping

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1 Introduction

Cheetahs are the fastest animals in the world [1]. One of the factors that influence this speed is their flexible and long trunk. It is well-known that the flexion and extension of the trunk increase their stride [2]. However, cheetahs not only have larger strides, but also larger stride frequencies compared to animals of the same size [3]. These facts mean that cheetahs are very powerful despite their slender bodies. Therefore, to explain the cheetah's speed, it is necessary to determine why cheetahs can generate such large power. Solving the mechanism will not only satisfy biological curiosity, but also provide clues for the design of quadruped robots that can achieve agile performance like animals.

Previous studies on biomechanics implied that the elastic energy stored in the trunk is a significant influencer of the powerful running of quadrupeds [4]. The trunk contains large ligaments, and elastic energy is stored in these tissue as the spine shape deforms (Fig.1, a) [4]. Many researchers have regarded the flexed spine shape of quadrupeds as the curve which has only one peak (C-shaped flexion model) [6, 7]. The C-shaped flexion model explains the stride expansion, but not the mechanism of generating the remarkable power of cheetahs.

In this study, we attempt to explain the powerful galloping of cheetahs by introducing a new spine flexion shape model with two peaks (S-shaped flexion model). We observe that if the abdominal and back muscles are simultaneously active, the anterior half of the spine flexes upward whereas the posterior half flexes downward more tightly (Fig.1, b). The local tight flexion of the S-shape could generate a stronger repulsion force of the spine than the overall loose flexion of the C-shape. In this study, we evaluate the relation between the flexion shape of the spine and the power generated from the spine through the experiments using the spine-catapult robot. The results showed the validity of the the S-shaped flexion model.

2 Model

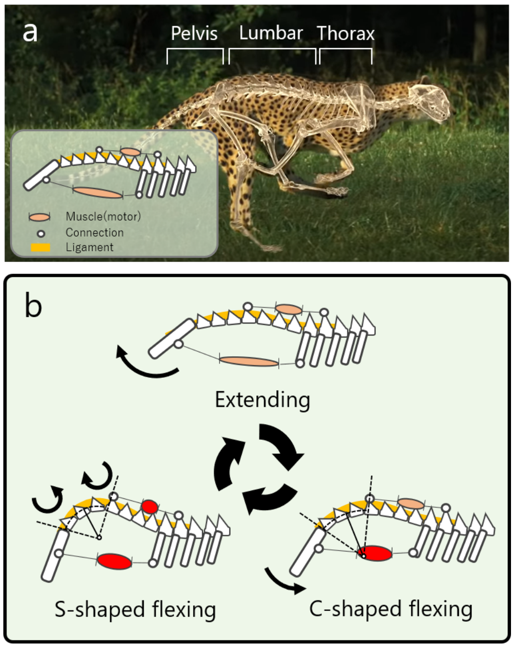

Figure 1: (a) Cheetah anatomy model [5]. (b) Proposed spine flexion-extension cycle in cheetah galloping.

In this section, we present the configuration of the spine-catapult robot. The entire body of the robot is shown in Fig.2. The robot consists of the spine unit consisting of the thorax, lumbar, and pelvis, wheels freely rotatable attached to the thorax and rear legs attached rigidly to the pelvis. The parts corresponding to the front legs of quadrupeds are simplified as wheels to focus on the effect of the spine motion. In addition, a one-way ratchet mechanism is implemented at the tip of the rear legs to remove contact friction when moving forward. In the spine unit, an elastic steel plate penetrates the lumbar vertebrae as the back ligament of the quadrupeds.

The robot is driven by four actuator modules; two of them are installed on the dorsal side, whereas the other are installed on the ventral side of the thorax. These modules consist of a tension line and line pull-up/release mechanism, driven by two RC servos. The dorsal actuator modules are stretched between the dorsal surface of the thorax and the protrude of the 4th lumber vertebra, whereas the ventral actuator modules are stretched between the ventral surface of

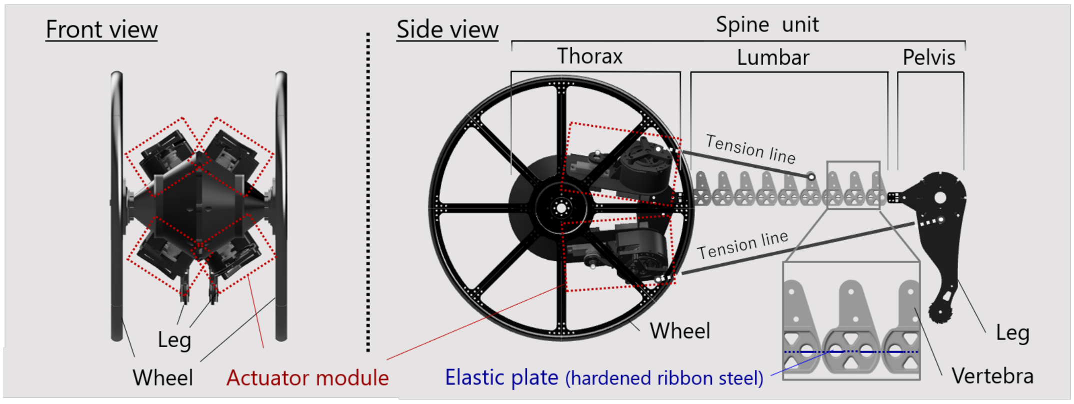

Figure 2: Full body configuration of a spine-catapult robot.

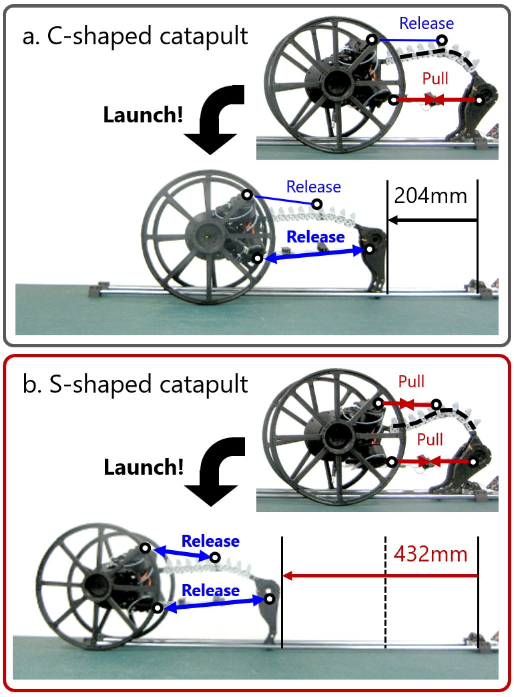

Figure 3: Horizontal jumping distance from different flexion shapes of the spine. (a) C-shaped flexion. (b) S-shaped flexion.

the thorax and that of the pelvis. By changing the states of these actuator modules, the robot jumps horizontally from the C-shaped flexion state or the S-shaped flexion state.

3 Results

We measured the horizontal jumping distance of the spine-catapult robot from the C-shaped flexion state and S-shaped flexion state. Each state during flexion and after jumping, respectively, are shown in Fig.3. In the C-flexion shaped state, only the ventral modules are pulled, and in the S-flexion state, both the ventral and dorsal modules are pulled before extension. The distance of jumping after extending the spine was more than twice for the S-shaped flexion compared to the C-shaped flexion. This result confirms that the S-shaped flexion is suitable for generating higher power when kicking by rear legs than C-shaped flexion.

4 Conclusion

In this study, we proposed a new spine flexion model of galloping cheetahs with two peaks (the S-shaped flexion model). We evaluated the effect of the flexion shape of the spine on horizontal jumping ability of quadrupeds. The results showed that the S-shaped flexion increases the repulsive force generated by the spine compared with the C-shaped flexion. In the future, we would like to build a new gallop running cycle model including the S-shaped flexion state to realize high speed gallop running by a quadruped robot.

Acknowledgements

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