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Simulation of quadruped robot walking considering anatomical features of distal forelimb

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1 Introduction

Felines use their forelimbs to perform a wide variety of actions such as walking, climbing trees, and attacking prey [1]. In order to realize these movements, the structure of the distal forelimb, which comes into contact with the environment or prey, is considered important. We have been investigating how the distal forelimb contributes to the realization of these movements. Clarifying this will help us gain biological insights as well as improve the performance of quadruped robots.

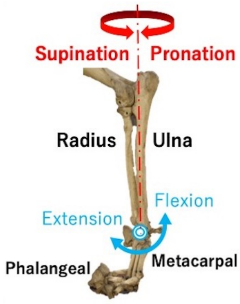
The morphological characteristics [2] and mobility [3] of the distal forelimb have been investigated, and it has been reported that these factors are important in achieving movement. However, the functions of the distal forelimb structure in realizing these movements remain unclear. In this study, we address this issue based on a synthetic approach. Specifically, we perform a walking simulation of a quadruped robot that introduces the structure of the distal forelimb to understand its function.

2 Biological findings on the distal forelimb

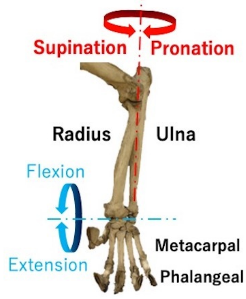
In this study, we focus on the structures of the forearm and wrist in the distal forelimb. In this section, the structures of the forearm and wrist are described. Next, we describe the behavior of the forearm and wrist during walking, based on an observation of lions in our previous study [4].

2.1 Structure of the distal forelimb

Fig. 1 shows the structure of the distal forelimb of a lion. The forearm consists of the radius and ulna. The radius can rotate around the long axis of the ulna (red arrow), which is called pronation/supination. The bones of the hand are articulated with the radius at the wrist joint and can be flexed to the palmar side (blue arrow). In addition, the wrist joint is interlocked with the elbow joint by muscles. Accordingly, the wrist can also be flexed when the elbow is flexed; however, the wrist is fixed in a straightened position by this interlocking when the elbow is extended.



(a) Outside view.



(b) Front view.

Figure 1: Skeleton of a lion's left distal forelimb.

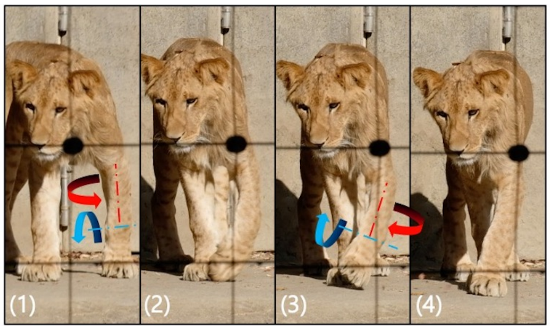


Figure 2: Snapshots of a walking lion.

2.2 Distal forelimb behavior while walking

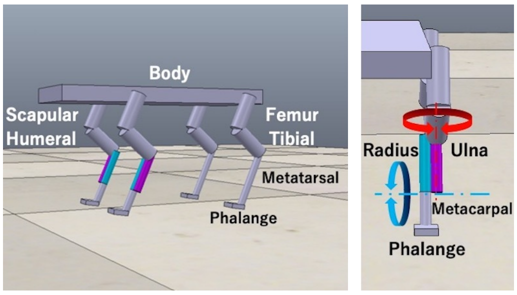
We observed several lions in the Yagiyama Zoological Park (Miyagi, Japan). Fig. 2 shows a lion while walking. The following findings can be derived from this figure:

(1) When the left forelimb leaves the ground, the forearm is supinated (red arrow) and the wrist is flexed (blue arrow).

(2) During the swing phase, the forearm is in the supinated position, and the wrist is in the flexed position.

(3) The wrist is extended (blue arrow), and the forelimb touches the ground. Then, the forearm is pronated (red arrow).

(4) During the stance phase, the forearm is in the pronated position, and the wrist is in the extended position.



(a) Overview. **(b)** Details of the left front leg.

Figure 3: Schematic of the proposed model.

3 Proposed model

We propose a model of a quadruped robot model, which considers the structure of the distal forelimb. The schematic of the model is shown in Fig. 3a. The robot has a torso consisting of a single link, and front and rear legs consisting of multiple links. The front leg comprises six links: scapular, humeral, ulnar, radius, metacarpal, and phalange links. Although the metacarpal and phalange are separated by fingers, they are represented as a single mass for simplicity. The rear leg consists of four links: femur, tibial, metatarsal, and phalange links. For simplicity, the link lengths of the rear leg are matched to those of the front leg as much as possible.

Details of the left front leg are shown in Fig. 3b. In accordance with anatomical futures, the radius link is articulated with the ulna link, and the bones of the hand (in this paper, metacarpal and phalange links) are articulated with the radius link. In addition, because the forearm and wrist are the focus of this study, their mechanical characteristics are introduced. In the forearm, we introduce elasticity, which is considered to be produced by muscles. In the wrist, we introduce the interlocking described in Section 2.1. Specifically, when the elbow is extended beyond a certain point, it is fixed in a straight position.

4 Simulation

CoppeliaSim [5] is adopted as the simulator. The front (rear) legs have rotational actuators at each of the three proximal joints, which control the position of the tip of the metacarpal (metatarsal) in an elliptical orbit. In order to introduce walking trot as a gait, the legs on the diagonal are set to move synchronously. Except for the above-mentioned joints, all other joints are passive; in the forearm and wrist, we introduce mechanical properties as described in Section 3. In addition, metacarpal (metatarsal) and phalange links are articulated in a fixed joint.

The ground reaction force and joint angles of the forearm and wrist in the left forelimb are plotted in Fig. 4. The joint angle of the forearm is defined as follows: the smaller the number, the more pronated is the limb; the larger the number, the more supinated is the limb. The joint angle of the wrist is described as follows: the smaller the number, the more extended (straight at 0) the limb; the larger the number, the more flexed the limb. Considering the joint angle of the forearm in Fig. 4, it can be verified that the forearm is supinated during the swing phase and pronated during the stance phase. Furthermore, considering that of the wrist in Fig. 4, it can be verified that the wrist is flexed during the swing phase and extended straight during the stance phase. These behaviors are consistent with the behavioral observations in Section 2.2.

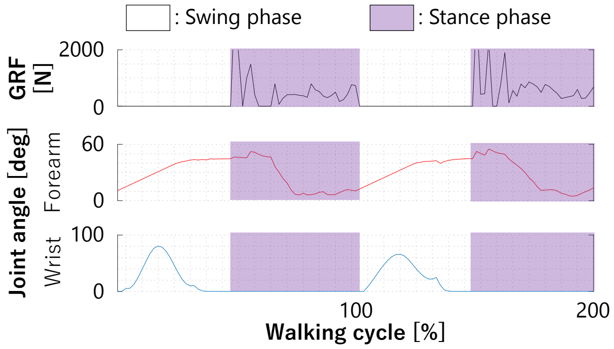


Figure 4: Left forelimb ground reaction force (GRF) and left forearm joint angle.

5 Conclusion

In this study, we performed a walking simulation of a quadruped robot, which introduced the structure of the distal forelimb, and succeeded in reproducing the walking behavior observed in lions. In other words, it is suggested that during walking, movement of the distal forelimb is not controlled by active control but by mechanical characteristics. In the future, we aim to manufacture actual machines.

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