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Toward understanding design principle of polysemantic body underlying animal’s versatile behaviors

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1 Extended abstract

Animals can instantly exhibit versatile behaviors to survive, depending on the situation. For example, many animals chase their prey or run away from predators. Furthermore, animals also show the versatile ability to feed, utilize tools, nest, and breed in response to their niches.

Fascinated by these adaptive animal behaviors, many researchers have attempted to understand the source of animal intelligence, and concepts of embodiment and morphological computing have been proposed [1,2]. Based on these concepts, animals' adaptability can be attributed to interactions between nervous systems (e.g., the brain and decentralized nervous system), flexible body, and environment rather than only the computation in the brain. To date, researchers have investigated the essential mechanisms guiding different animal species and influencing their behaviors [3,4]. However, the ability of animals to exhibit versatility in coping with unpredictable situations remains an open question.

In this study, we focused on the situation-dependent multifunctionality of animals’ bodies to understand the sources of animals' versatility (Fig. 1). For example, carnivorous quadrupeds (e.g., lions) exploit their forelimbs as locomotor organs during walking and running and as a manipulator during feeding. Quadrupeds with large heads and necks (e.g., horses and giraffes) apply a wide range of motion for their necks for feeding and manipulating; during locomotion, they swing their neck as a counter-mass for efficient movement. Thus, a particular body part can exhibit distinct functions through interactions with different environments and situations, and the anatomical characteristics (e.g., the limitation of the joint angle and the connectivity of myofascia) likely contribute to the situation-dependent functionality. We call such a clever animal body with situational adaptability “polysemantic body” and investigate its design principles. We expect that the understanding of the influence of polysemantic bodies on versatile animal behaviors will be helpful in a novel robot design, in which a single modular unit can perform various functions, depending on the situation.

To achieve this aim, the authors, from robotics and anatomy fields, jointly developed bioinspired robots to analyze how focused anatomical structures in quadrupeds (mainly mammals) contribute to specific tasks. In this demonstration, we present our developed robots and discuss functional polysemy in animal mechanical systems and control mechanisms.

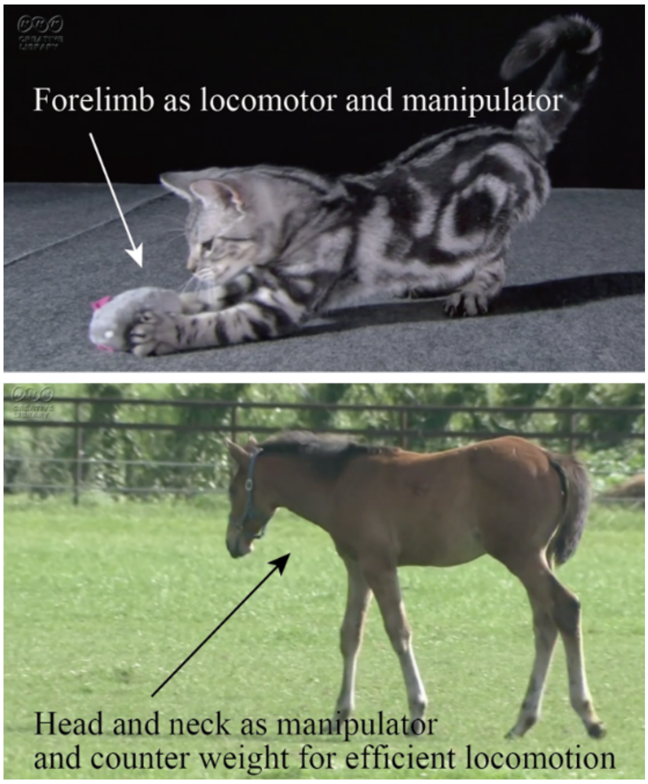

Figure 1: Polysemy in animal versatile behaviors. (Pictures from NHK Creative Library: https://www.nhk.or.jp/archives/creative/en/)

All authors contributed to this work equally.

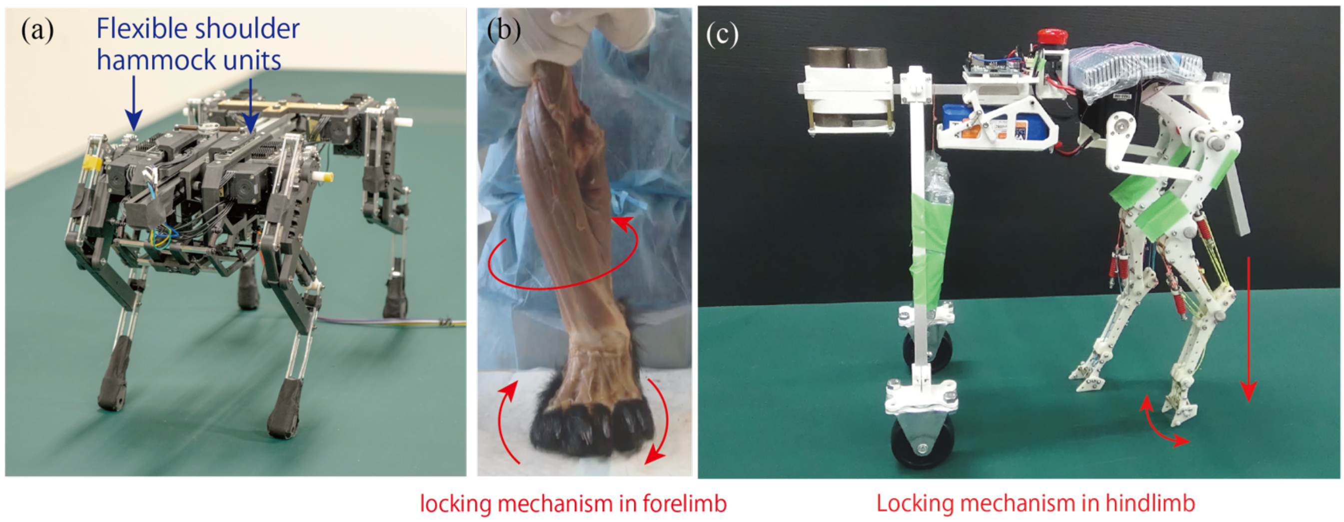

Figure 2: Our robots and anatomical model in Robot Zoo. (a) Quadruped robot with flexible shoulder hammock structure [5]. (b) Flesh sample of forearm of carnivorous quadruped (Asiatic black bear). (c) Musculoskeletal robots mimicking hindlimbs of horse [7].

2 Contents of demonstration

In Robot Zoo in AMAM2021, we present the bioinspired quadruped robots developed to investigate the polysemantic body influencing versatile animal behaviors. First, we begin by analyzing how the focusing of the anatomical structure contributes to a specific task (e.g., locomotion) before investigating the transition mechanism between tasks.

For example, we focus on different connectivities to the trunk between the forelimbs and hindlimbs in cursorial quadrupeds (e.g., dogs and horses). While the hindlimbs securely connect to the pelvis through the deep ball-and-socket joint (hip joint), the forelimbs flexibly connect to the chest through several muscles (e.g., serratus and trapezius muscles). To examine the functionality of the flexible shoulder region, we developed a simple body model for a physical robot [5] and simulations [6]. In actual robot experiments (Fig. 2(a)), the flexible connection at the base of the forelimbs absorbs the mechanical loads of the landing moment from an elevated location. In other tasks, e.g., locomotion, the simulation experiments show that the flexible shoulder region of the robot contributed to reconciling the different vertical motions between the forelimbs and the hindlimbs while walking. Consequently, the trunk posture stabilizes, and the robot achieves efficient walking. In the demonstration, we show the developed quadruped robot with flexible shoulders in falling and walking tasks.

In another example, we focus on the locking mechanisms of joints from the musculoskeletal system in quadrupeds. The forearms of carnivorous quadrupeds (Fig. 2(b)) and hindlimbs of horses (Fig. 2(c)) exhibit a unique mechanism in which the joints are locked and support the body weight automatically by placing the tip of the toe on the ground. To investigate the contribution of the locking mechanisms during walking, we developed a robot model [7] that replicates the muscle-tendon structure of a horse hindlimb. In the walking experiments, the robot model exhibits a steady walking motion with a smooth transition between the swing and stance phases by swinging the hip joint with a sinusoidal input. The comparison between the successful and failed steps shows that the extension of the fetlock joint generated by the interaction with the ground contributes to joint locking and reliable body support during the stance phase. In the demonstration, we show the robot model of a horse hindlimb that walks smoothly through musculoskeletal interaction with the ground.

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References

[1] R. Pfeifer and J. Bongard: How the body shapes the way we think. MIT Press, 1999.

[2] R. Pfeifer and G. Gabriel: Morphological computation–connecting brain, body, and environment. *Creating brain-like intelligence*. 66–83, 2009.

[3] A.J. Ijspeert: Biorobotics: Using robots to emulate and investigate agile locomotion. *Science*, 346: 196–203, 2014.

[4] N. Gravish and G.V. Vauder: Robotics-inspired biology. *Journal of Experimental Biology*, 221, deb138438, 2018.

[5] A. Fukuhara, Y. Masuda, M. Gunji, K. Tadakuma, and A. Ishiguro. Development of quadruped robot that can exploit shoulder hammock structure. In *IEEE/SICE SII2020*, 1139–1143, 2020.

[6] A. Fukuhara, M. Gunji, Y. Masuda, K. Tadakuma, and A. Ishiguro: A bio-inspired quadruped robot exploiting flexible shoulder for stable and efficient walking. In *IEEE/RSJ IROS2020*, 7832–7839, 2020.

[7] K. Miyashita, Y. Masuda, M. Gunji, A.Fukuhara, K. Tadakuma, and M. Ishikawa: Emergence of swing-to-stance transition from iInterlocking mechanism in horse hindlimb. In *IEEE/RSJ IROS2020*, 7832–7839, 2020.