Towards emulating adaptive locomotion of a quadrupedal primate by a neuro-musculo-skeletal model

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Morphologies of locomotor organs in primates are well correlated with their primary locomotor behaviors. Biomechanical studies also suggest that primary locomotory pattern, bipedal locomotion in human and brachiation in gibbon, is induced as the natural oscillation pattern of the body linkage determined by its body proportion. These findings imply that locomotion is basically generated so as to adapt and depend upon the structures of body system formed rationally through the evolutional process.

Locomotion of animals, including that of primates, is often regarded adaptive in terms of robustness against environmental changes and unknown perturbations. However, there are actually two sides in adaptive mechanism of animal locomotion; to the environment, and as implied above, to the body structure.

Such two-fold adaptivity of primate locomotion can be hypothesized to be emerged by dynamic interaction between the nervous system and the musculo-skeletal system. A network of neurons recurrently connecting to the others can be viewed as a dynamical system which autonomously behaves based on a minimization principle; it behaves convergently to decrease an energy function defined in it. Moreover, a body is also a dynamical system which has a passive properties due to its physical characteristics such as segment inertial parameters and joint mobility. If these dynamical systems are mutually connected, as they are in biological systems, appropriate constraints may be self-organized because of the convergent characteristics of the both systems, and the adaptive nature of the primate locomotion could be spontaneously emulated.

In the present study, therefore, a neuro-musculo-skeletal model of a quadrupedal primate is constructed based on the above mentioned idea.

A quadrupedal primate is modeled as a 16-segment, three-dimensional rigid body kinematic chain. The dimensions and inertial parameters of the model are determined from a female Japanese macaque.

The nervous system is modelled as the recurrent neural network, inner states of neurons of which represent ground reaction forces. The neural network is designed so as to spontaneously compute ground reaction forces necessary to maintain its posture based on the multi-modal sensory inputs, due to the neuro-dynamics implemented in the system. The joint torques are then generated accordingly. The rhythm pattern generator, which coordinate sequential limb movement in a quadrupedal animal, is also modelled and combined with the recurrent neural network.

The simulated results show that the proposed model can adapt to maintain its posture against external perturbations. Moreover, the model can generate stepping motions. The generated motions are not preplanned at all; but it is naturally and spontaneously yielded by the natural behavior of the combined dynamics of the neural circuit and the passive body. Therefore, the generated motions become adaptive, to the environment and to the body structure.

The proposed framework for the integrated adaptive control of posture and locomotion seems reasonable as well as biologically feasible; therefore, it may be extended for elucidating the adaptive mechanism of primate locomotion in future studies.