An analytical study of the cost of transport for legged locomotion

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1. Introduction

It has been known that locomotor patterns of many legged animals show common characteristics, which suggests that there exists a basic strategy for legged locomotion. In this study we examine the minimization of the cost of transport as a candidate of the strategy. For this purpose we derive an equation to estimate the cost and compare the characteristics of observed locomotor patterns and those of the optimal one minimizing the cost.

2. Estimation of the cost of transport

We estimate the energetic cost during locomotion as the sum of the mechanical work to move legs and the heat energy loss due to torque generation which is assumed to be proportional to the square of produced joint torque. An equation to estimate the cost of transport, the cost to move a unit mass a unit distance, was analytically derived under some assumptions.

3. The optimal locomotor pattern

The optimal locomotor parameters minimizing the cost of transport was computed. The characteristics of the optimal pattern were well coincident with those of observed patterns, e.g., as locomotion velocity increases, the duty ratio, the ratio of a stance duration to a stride period, and a stride period decrease but a stance length and a swing duration take almost constant values [1, 2, 3, 4, 5]. The optimal duty ratio shows graded change when the ground reaction forces to stance legs are set as a time-independent constant value. However, when considering more realistic distribution of the ground reaction forces, the duty ratio tends to stay at specific values in some ranges of locomotion velocities and shows non-graded change, which means the emergence of stable gait patterns, such as a wave gait and a quadrupod gait, and the phase transition between them (Fig.1). The different distribution of the ground reaction forces resulted in the different set of stable gait patterns, which suggests that the body structure which affects the distribution of ground reaction forces would determine the optimal set of gait patterns.

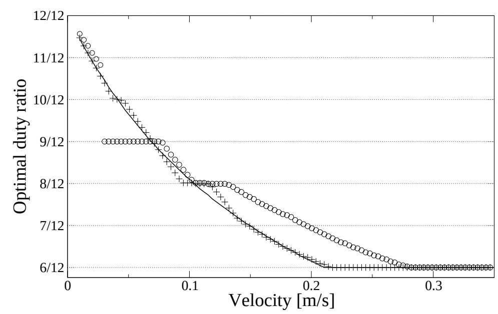

Figure 1: The optimal duty ratio. The ground reaction force for each stance leg is set as a constant value (-), given by the body weight divided by the number of stance legs (+), and computed considering the balance of forces around a rigid body (o). The number of legs are set as 6.

4. Conclusion

The correspondence between observed locomotor patterns and the optimal one suggests that the derived equation to estimate the cost of transport well represents a key feature of the energetic cost determining the gait pattern and that locomotor patterns of legged animals are well optimized on the energetic cost. The existence of stable gait patterns and the phase transition between them observed in legged animals would be also results of the optimization.

References

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