Tail Use in Quadruped Improves Static Stability in Diagonal Sequence Walking Gaits

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Abstract

This work investigates the use of a tail to help stabilize larger-stride-displacement gaits for a quadruped robot. To limit the scope of our discussion, we consider two types of symmetric gaits: the lateral sequence and the diagonal sequence walking gaits [1]. In both gaits, all legs have the same duty factor, and the only difference lies in the sequence under which the feet are lifted from the ground. We observe that the lateral sequence gait has a smaller stride displacement but maintains more static stability (Fig.1), and in practice, most animals adopt this gait when walking [2]. On the other hand,

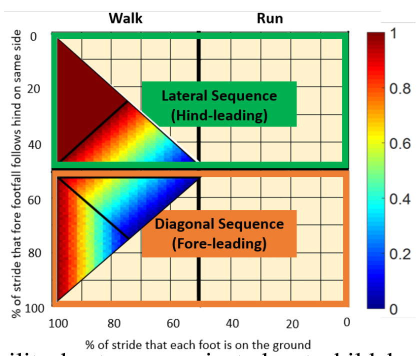


Fig. 1: stability heat map projected onto hildebrand diagram

the diagonal sequence gait produces a larger stride displacement (Fig.2) but at the cost of decreased static stability. The

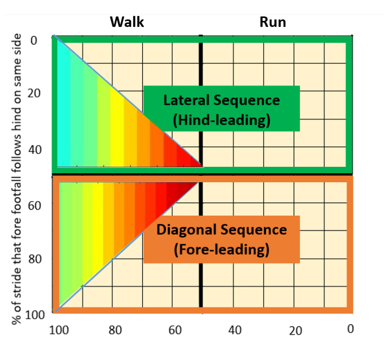
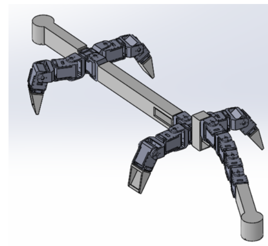
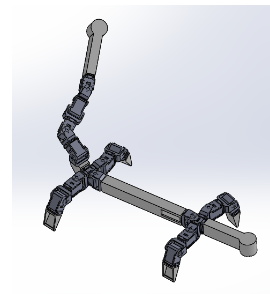


Fig. 2: stride displacement heat map projected onto hildebrand diagram

contribution of this work is to increase the static stability of the diagonal sequence walking gait by considering the use of an actuated tail (Fig.3(a) and Fig.3(b)). By coupling the motion of the tail with the body shape changes and derive tail function from stability heap map, we derive periodic tail oscillations that act as a counterweight and restrict the center of mass of the robot within its support polygon. Then we test our approach on a servo-driven, salamander-like robot that locomotes on

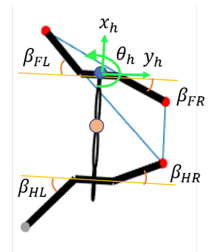


(a) the planar tail

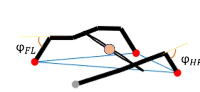


(b) the 2-plane tail

Fig. 3: two tail designs



(a) leg angle β and head position g_h



(b) elbow angle ϕ

Fig. 4: parameters

flat grounds using its four limbs, each with two degrees of freedom (up/down and fore/aft). Our model assumes that if the slip exists, it would occur in the leg opposite to the lifting leg. At every moment of a gait, shape variables β_i (leg angle) (Fig.4(a)) and their derivatives are known. Positions of diagonal feet on ground are known. The key is to find head position

$$g_h = \begin{bmatrix} x_h & y_h & \theta_h \end{bmatrix}^T \tag{1}$$

and elbow angle φ (Fig.4(b)) that ensures zero linear velocity for the diagonal legs, we have

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \dot{x}_{diagonalleg1} \\ \dot{y}_{diagonalleg1} \\ \dot{x}_{diagonalleg2} \\ \dot{y}_{diagonalleg2} \end{bmatrix} = \omega(r) \begin{bmatrix} \dot{g}_h \\ \dot{\beta} \\ \dot{\phi} \end{bmatrix}. \tag{2}$$

Then we can numerically calculate the stride displacement. A series of connected servos serve as a tail. We compare stride displacements of lateral sequence and stabilized diagonal sequence gait, showing that with the help of an actuated tail, such a quadruped can take advantage of the higher stride displacement ($\approx 30\%$ larger) of the diagonal sequence walking gait while maintaining static stability.

References

[1] Milton Hildebrand. Symmetrical gaits of horses. *science*, 150(3697):701–708, 1965.

[2] Milton Hildebrand. The quadrupedal gaits of vertebrates. *BioScience*, 39(11):766, 1989.