Floquet Stability of 7-Link Footed Biped Compliant Walking

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1 Motivation

Stability during human gait depends on a number of inter-related factors, such as gait trajectory, joint impedance and neural strategy for controlling active torques. Let us naively assume an "optimal" periodic desired trajectory for each joint angle during steady gait, with a set of simple feedback controllers for tracking. Does the gait stability increase as the feedback gains (thus, the joint impedance) increase? The answer can be interestingly negative, suggesting beneficial aspects of compliant gait dynamics for the stability. This is a preliminary study toward our motives for revealing neural control mechanisms for achieving compliant gait.

2 State of the Art

Gait stability issue relates to several aspects. First, controller. Grizzle team utilizes hybrid zero dynamics theory and finite time converging controller to realize multilink biped dynamic walking. Second, the Floquet stability, which has been successfully applied to analyzing passive biped [1] and active walking with dimension reduced Poincaré mapping [2]. Numerically calculated Floquet multiplier, dimension reduced Poincaré section, data-driven Floquet are effective ways. [3] has carried out experiment to discuss Floquet index on human falling. Third, foot contact. Hurmuzlu dealt with rigid impact. Todorov has studied planning through contact smoothing. [4] presents elastic contact influence on passive robot gait. Fourth, heavy trunk. Zajac [5] has discussed all joint moments contribute to trunk angular acceleration by experiments. McGeer and Wisse [6] develop passive model with upper body by adding impulse torque or bisecting hip mechanism. Fifth, regarding compliant joints, it can reduce energy consumption [7] and influence the gait [8]. We feel that one of current barriers is a lack of clear understanding of how the joint impedance contributes to stability of compliant walking.

3 Own Approach

Here we simply assume a time-periodic desired joint angle trajectory and linear PD feedback controllers, and ask how the gait stability depends on feedback gain parameters. We use a 7-link footed biped model [9] for which it has been demonstrated that there exists a small basin of attraction of a limit cycle when each of 6 joints angles is constrained by a periodic desired time course. Thus, the limit cycle solution of the constrained model is employed as a desired trajectory. We numerically explore a periodic solution (fixed point) for a varied set of PD gain parameters, and calculate Floquet multipliers in 18 dimensions to examine influence of the feedback gains on the Floquet multipliers.

4 Current Results

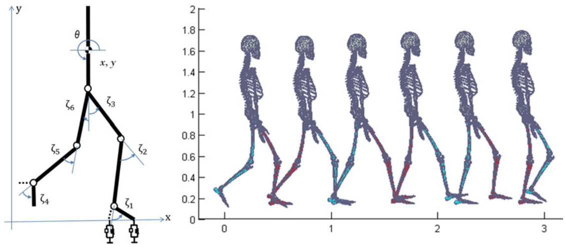

Fig. 1: A 7-link model and its stable walking achieved by a simple PD feedback control.

The model with compliant feet can perform natural walking with heel down and toe off as in Fig.1. Floquet multipliers are effectively calculated for those dynamic walking. As shown in Fig.2, non-monotonic dependency of the gait stability on the feedback gain parameters can be observed, meaning that the gait stability does not necessarily increase as the feedback gains (thus, the joint impedance) increase. Indeed, the most stable gait is located close to the stability boundary with almost the smallest values of the feedback gains.

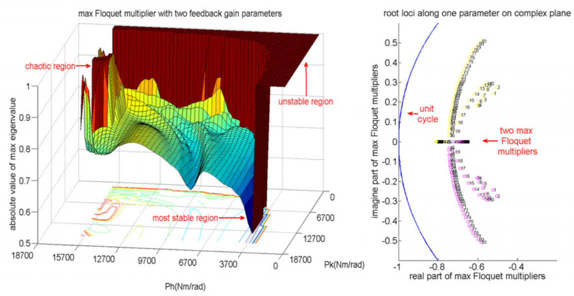

Fig. 2: Gait stability (left) and root loci (right) as functions of P_h (hip P gain) and/or P_k (knee P gain).

5 Best Possible Outcome

Further analysis will enable us to understand how the small feedback gain can provide the most stable gait, which will be a basis of dynamic modulation of gain parameters for more robust and compliant gait control.

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