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Uncertainty Analysis Using the Gap Metric Approach for a Single Leg of a Quadruped Robot

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1 Introduction

Robots are built to interact with humans and tools in different types of environment. One of the big issues for the control system design of robots is the existence of uncertainties that can move the operating point to an unexpected place causing instability and lose of performance. In special, legged robots experiences large variability in the mass of the legs, as well as other parameters, during the walk. Therefore, robust and adaptive control strategies are developed to handle the uncertainties problems such as the H_∞ control and gain scheduling, however there are drawbacks in each technique. The robust control for instance tends to generate high order controllers and to be very conservative besides the complex mathematical background involved in the robust control design. Based on that, this paper tries to overcome some of the issues of robust control using a relatively new mathematical tool in the control literature and applications called gap metric .

The gap metric measures the distance between two systems in terms of dynamic response and exhibits robustness properties. In general the range of values assumed by the gap is [0,1], 0 meaning that the systems are close and can be easily controlled by the same controller and 1 meaning that the systems are distant from each other making it difficult the simultaneously controller synthesis, stability and performance guarantee. There are different ways to calculate the gap metric between two systems and this paper presents the characteristic projection method and it's used for the study of parametric uncertainties in a quadruped robot. The problem is to calculate the distance between a nominal system P and an uncertain system P_Δ.

2 Results and Discussions

The gap metric between the nominal system P and the uncertain system P_Δ is:

$$\delta(P, P_\Delta) = \|\pi_P - \pi_{P_\Delta}\| \tag{1}$$

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Where π_i is the characteristic projection of the system i. The dynamic of the leg of a quadruped robot is defined by the following transfer function:

$$\frac{Z(s)}{U(s)} = \left(\frac{k}{m_l s^2 + bs + k}\right)\left(\frac{bs + k}{(m_l + m_b)s^2}\right) = P(s) \tag{2}$$

U(s) is the force control action and Z(s) is the position of the leg to be controlled.

Param.	Variation	Description
m_l	$\pm 50\%$	Leg mass
m_b	$-$	Body mass
k	$\pm 90\%$	Stiffness coefficient
b	$\pm 50\%$	Dumping coefficient

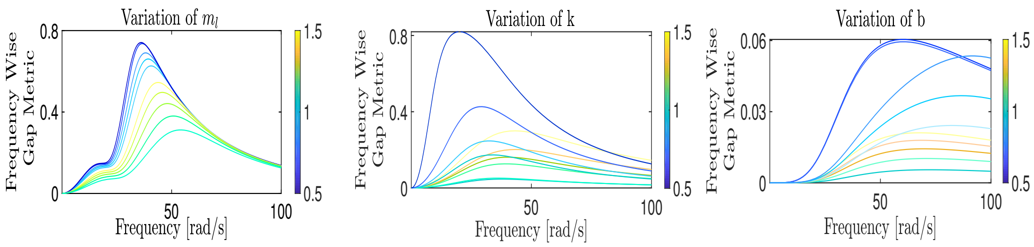

Figure 1: Gap metric between P(s) and $P_\Delta(s)$ in different situations of parameter variation

Some nice inferences can be made in terms of the study of uncertainty and the effect of it in a nominal robotic system just by looking the frequency wise gap metric in Figure 1:

1. The system shows higher sensibility to parameter variation when it's decreasing their values. The gap metric value grows for the decrease of leg mass, stiffness and dumping coefficient meaning a bigger distance in terms of dynamic response between the nominal and perturbed system

2. The variation of the dumping coefficient affects less the dynamic of the robot in this particular problem when compared with the two other parameters

3. The three parameters have better gap metric values in very low and very high frequencies. Therefore, the system can be better controlled in these frequency ranges

The gap metric must be compared with stability and performance factors in order to help with the controller synthesis and stability analysis. These three simulations results can be used to assist the control system design of the legged robot used in this letter.

References

[1] K. Zhou and J.C. Doyle. *Essentials of robust control*. Prentice Hall Upper Saddle River, 1998.