Balanced Region-based Analysis of Push Recovery Control using Ankle and Hip Strategies

Hyunjong Song*
Department of Mechanical and Aerospace Engineering
New York University
Brooklyn, NY, USA
*Contributed equally

William Z. Peng*
Department of Mechanical and Aerospace Engineering
New York University
Brooklyn, NY, USA
*Contributed equally

Joo H. Kim
Department of Mechanical and Aerospace Engineering
New York University
Brooklyn, NY, USA
Email: joo.h.kim@nyu.edu

***Abstract*—The balanced region obtained for a biped robot in double support contact is applied to the analysis of its response to forward perturbations without stepping. The performance of a gyro feedback controller and a hip and ankle strategy-based controller are evaluated in simulation relative to the push recovery capability of the system represented by the balanced region.**

I. INTRODUCTION

There exists a lack of explicit criteria in the balance stability literature that can distinguish between whether a legged system is falling or not. Without explicit criteria, approaches to balance control resort to tuning the parameters associated with various known push recovery strategies (e.g., hip, ankle, and stepping strategies [1]), leading to controller-specific stability regions that do not exploit the full balancing capability of the system.

II. BALANCED REGION DEFINITION AND FORMULATION

A legged system is balanced if and only if it can remain indefinitely within its specified contact (e.g., double support (DS)) without having to modify its original contact. Otherwise, the system is unbalanced. Furthermore, the set of unbalanced states can be partitioned into steppable and unsteppable regions based on whether the system can reach a desired step length from a given state with its actuation and kinematic limits. A state is classified as falling if and only if it is both unsteppable and unbalanced. When considering the center of mass (COM) position and velocity of a system, these partitions define balanced regions of COM-state space that are the superset of all controller-specific stability regions (i.e., the reachable space for all possible controllers). Falling can still occur within the balanced region depending on the implemented balance controller. The boundary of these regions can be obtained as the solutions to a series of constrained optimization problems.

III. PUSH RECOVERY CONTROL

A. Gyro feedback controller

The default controller for the biped robot DARwIn-OP regulates the pelvis angular velocity with simple *P* control. The feedback controller alters the angle bias of the knee $\Delta\theta_{knee} = K_{knee}\omega_{gyro}$ and ankle $\Delta\theta_{ankle} = K_{ankle}\omega_{gyro}$ where K_{knee} is the knee control gain, K_{ankle} is the ankle control gain, and ω_{gyro} is the angular velocity measured by the gyro sensor attached to the torso of the robot in the simulation environment [2]. The values of K_{knee} and K_{ankle} are tuned manually.

B. Hip and ankle strategy-based controller

Both the hip and ankle strategy are needed in response to large perturbations when stepping is not. An existing hip and ankle strategy-based controller for the biped robot and simulation environment was implemented [3]. The ankle strategy regulates the COM-state with *PD* control by adjusting the angle bias of the ankle $\Delta\theta_{ankle} = K_p x + K_d \dot{x}$, where x is the COM *X*-position, $\dot{x}$ is the COM *X*-velocity and K_p and K_d are the respective *PD* gains.

The hip strategy is based on a bang-bang control strategy that sets the hip joint bias $\Delta\theta_{hip} = \theta_{hip}^{\max}$ for $0 \le t < 2T_{H1}$ and $\Delta\theta_{hip} = \theta_{hip}^{\max}\left(2T_{H1} + T_{H2} - t\right)/T_{H2}$ when $2T_{H1} \le t < 2T_{H1} + T_{H2}$ where $\theta_{hip}^{\max}$ is the maximum hip angle, t is the time after perturbation, and the times T_{H1} and T_{H2} are control parameters.

IV. RESULTS AND DISCUSSION

Incorporating both hip and ankle strategies for push recovery outperformed the gyro feedback controller (Fig. 1). The hip and ankle strategy-based controller was also better able to exploit the full balance capability represented by the balanced region.

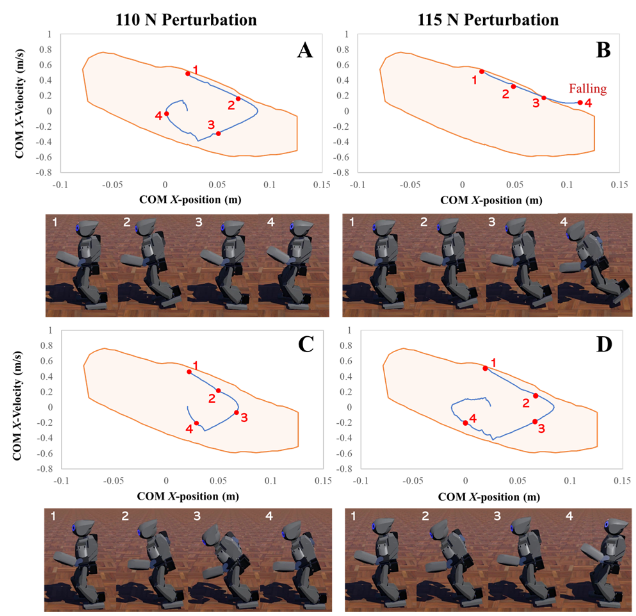

Fig. 1. COM trajectories with respect to the balanced region of the system (shaded) after a perturbation of 110 N (A and C) and 115 N (B and D) is applied for 16 ms to the gyro feedback controller (DARwin-OP's default controller) (A and B) and hip and ankle strategy-based controller (C and D). The system remains balanced in all cases except when the 115 N perturbation is applied to the gyro feedback controller (B).

REFERENCES

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