Disturbance Observer Based HZD Control of Biped Walking and Slip Recovery

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1 Introduction

Robust walking under various ground condition is required for application of biped robots. Some researches deal with the biped robot control considering foot slip as [1] and [2]. However, few research deal with recovery control after slip. Our work presents balance recovery trajectory design and disturbance-observer (DOB) based control [3]. Balance recovery trajectory is designed through slip recovery gait of human [4]. DOB requires only nominal model, and realizes a precise and robust control system [5].

2 Method

Disturbance observer (DOB) uses a linear nominal model to approximate the plant dynamics and the model errors for robust feedback design. For the bipedal model, actual mass matrix $\boldsymbol{D}$ and the motor torque constant $\boldsymbol{K}_t$ can be expressed as

$$\boldsymbol{D} = \boldsymbol{D}_n + \Delta\boldsymbol{D},\ \boldsymbol{K}_t = \boldsymbol{K}_{tn} + \Delta\boldsymbol{K}_t, \qquad (1)$$

where subscript "n" and prefix symbol Δ denote the nominal value and the model error of these parameters, respectively. Considering torques $\boldsymbol{u} = \boldsymbol{K}_t \boldsymbol{I}^{\text{ref}}$, where $\boldsymbol{K}_t = \text{diag}\{K_{t2}, K_{t3}\}$ is the motor torque gain and $\boldsymbol{I}^{\text{ref}} = [I_2^{\text{ref}}\ I_3^{\text{ref}}]^T$ is the motor current for two joint motors. Substituting (1) into motion equation, we obtain

$$(\boldsymbol{D}_n + \Delta\boldsymbol{D})\ddot{\boldsymbol{q}} + \boldsymbol{C}\dot{\boldsymbol{q}} + \boldsymbol{G} = \boldsymbol{B}(\boldsymbol{K}_{tn} + \Delta\boldsymbol{K}_t)\boldsymbol{I}^{\text{ref}} - \boldsymbol{\tau}^{\text{ext}}, \qquad (2)$$

where $\boldsymbol{\tau}^{\text{ext}}$ is the external torque. Eq. (2) is further transformed as

$$\boldsymbol{D}_n\ddot{\boldsymbol{q}} = \boldsymbol{B}\boldsymbol{K}_{tn}\boldsymbol{I}^{\text{ref}} - \boldsymbol{\tau}^{\text{dis}} \qquad (3)$$

$$\boldsymbol{\tau}^{\text{dis}} = \boldsymbol{\tau}^{\text{ext}} + \Delta\boldsymbol{D}\ddot{\boldsymbol{q}} - \boldsymbol{B}\Delta\boldsymbol{K}_t\boldsymbol{I}^{\text{ref}} + \boldsymbol{C}\dot{\boldsymbol{q}} + \boldsymbol{G}, \qquad (4)$$

where $\boldsymbol{\tau}^{\text{dis}}$ is the disturbance torque. By estimation and compensation of $\boldsymbol{\tau}^{\text{dis}}$ by DOB [5], Nominalized dynmaics is realized as (3).

Trajectory planning is designed based on the framework of hybrid zero dynamics (HZD) [6]. For normal walking, the virtual constraints are designed to mimic the human subject's knee to hip and toe to hip relative position. For slip recovery, the desired motion is designed by certain principles such as "touch down the swinging foot as soon as possible", "give high knee torque to prevent COM from dropping down". According to these principles, joint torques are directly given to simulate the motion. Virtual constraints for slip recovery are obtained by fitting bezier polynomial to the desired simulated joint angle trajectories.

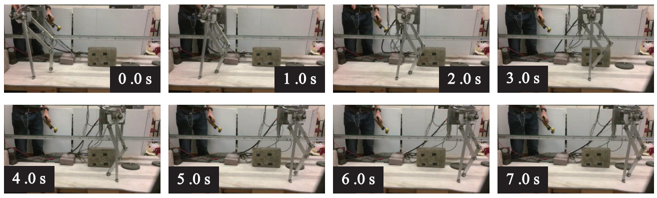
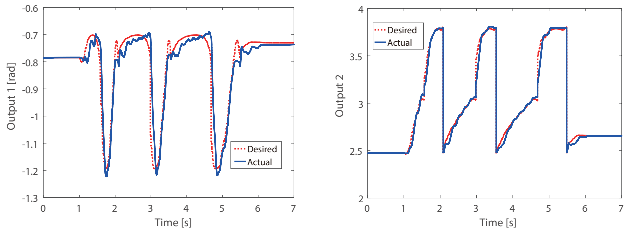


Figure 1: Snapshot of the normal walking experiments.



(a) (b)

Figure 2: Experimental results of normal walking. (a) Output 1. (b) Output 2.

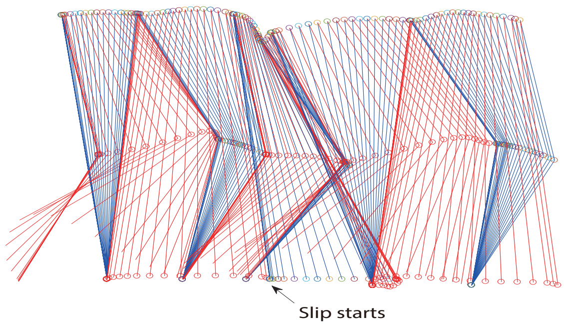


Figure 3: Stick snapshots of the slip walking simulation.

3 Result and Discussion

Fig. 1 shows the snapshot of the gait profile under the DOB-based control design. It is clearly observed from these experimental results that normal walking is attained properly. The output tracking performance is shown in Figs. 2 (a) and (b). Under the DOB-based controller, the actual outputs follow the desired trajectories closely.

Fig. 3 shows stick snapshots of the slip walking simulation with DOB enhanced feedback linearization (FBL) controller. The robot experiences slip phase when the straight leg is slipping and the bended leg is swinging. The bended leg then touches down and tries to support the COM. The robot should have enough momentum to fall forward in order to recover to the normal walking gait. In the plotted stick snapshots, slip recovery is achieved.

4 Conclusions and Future Works

A slip recovery control of bipedal robotic walkers using DOB is proposed. We presented a human-inspired walking gait profiles for both non-slip and slip locomotion. DOB-based control is implemented to non-slip normal walking experiment. Normal walking is attained propoerly and high tracking performance is observed. Walking with slip recovery is demonstrated successfully by DOB-enhanced FBL controllers.

We are currently implementing the DOB-based slip recovery control design in experiments. Integration of the slip detection algorithm [7] with the recovery control is another ongoing research task.

Acknowledgments

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