

**Applied Dynamics &** Optimization Lab

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





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### **BACKGROUND AND OBJECTIVES**

- Empirical data-driven approaches are used for parameter tuning in balancing controllers for biped robots
- □ The controller-specific stability region obtained for a robot may not reflect the full balance capability of the system
- □ In this work, a non-controller-specific stability region is computed and applied to push recovery without stepping

# **STATES OF BALANCE – DEFINITIONS**

**BALANCED** vs. **UNBALANCED** states are defined <u>relative to</u> a <u>specified</u> <u>contact</u> configuration [1]:

### **RESULTS AND DISCUSSION**

□ Addition of knee strategy to existing hip and ankle strategy-based controller:

- Reduced balancing time from 1.66 s to 0.96 s
- Reduced maximum stance foot tilt angle from 13.98 to 0.000024 degrees



#### **Gyro feedback controller**

#### **Hip and Ankle Strategy-based Controller**





**Figure 1:** Example of balanced and unbalanced states relative to a single support (SS) contact configuration. These definitions hold for any generic multi-contact configuration.

**BALANCED state**: There exists a (controlled) trajectory starting from a given legged system's state such that the system does not ever alter its contacts

**UNBALANCED state:** All (controlled) trajectories starting from a given legged system's state will lead to an inevitable change in the system's contacts

## **PUSH RECOVERY CONTROL**

Existing push recovery controllers for the DARwIn-OP humanoid robot

- Gyro feedback controller (default controller for DARwIn-OP) [2]
- Hip and ankle strategy-based controller [3]

□ Implemented hip, knee, and ankle strategy-based controller

Additional P control of the knee angle bias based on extremized joint profiles from optimization results





Hip, Knee, and Ankle Strategy-based Controller



Figure 3: COM trajectories in response to perturbations of 110 N (left) and 115 N (right) with a duration of 16 ms. The balanced region (shaded) corresponds to a double support contact configuration with a step length of 0.057 m. The system remains balanced in all cases except

**Figure 2:** Schematic of implemented hip, knee, and ankle strategy-based controller

### when the 115 N perturbation is applied to the gyro feedback controller.

### CONCLUSIONS

- □ Stability regions are general balance criteria that include all possible controller-specific stability regions
- Use of stability region analysis was demonstrated for push recovery control

#### REFERENCES

#### **A**CKNOWLEDGEMENTS

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WHERE DISCOVERIES BEGIN

**National Robotics Initiative** 

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