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 relative to a specified contact configuration [1]:

  ![Example of balanced and unbalanced states relative to a single support (SS) contact configuration. These definitions hold for any generic multi-contact configuration.](Image)

  **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

![Schematic of implemented hip, knee, and ankle strategy-based controller](Image)

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

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

![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 when the 115 N perturbation is applied to the gyro feedback controller.](Image)

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 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