

ASSESSMENT OF STABILIZING FEEDBACK CONTROL OF WALKING, A TUTORIAL

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ABSTRACT

Walking without falling requires stabilization of the trajectory of the body center of mass relative to the base of support. Model studies suggest that this requires active, feedback control, especially in the mediolateral direction. In older adults and in individuals with neurological or orthopedic disorders that affect walking ability, falls during gait are a common cause of injuries, hospitalization and loss of independence. In this tutorial, we illustrate how gait analysis can be used to assess the stabilizing feedback control of gait. We present methods ranging from those that require limited input data (e.g. position data of markers placed on the feet and pelvis only) to those that require full-body kinematics and electromyography. Analyses range from simple kinematics analyses to inverse dynamics. These methods assess stabilizing feedback control of human walking at three levels: 1) the level of center of mass movement and horizontal ground reaction forces, 2) the level of center of mass movement and foot placement and 3) the level of center of mass movement and the joint moments or muscle activity. We show how these can be calculated and provide a GitHub repository (<https://github.com/VU-HMS/Tutorial-stabilizing-walking>) which contains open access Matlab and Python code to calculate these. Finally, we discuss what information on feedback control can be learned from each of these.

1. INTRODUCTION

Preventing a fall while walking requires stabilization of the position of the body center of mass over the base of support. The common occurrence of falls in toddlers who learn to walk, illustrates the difficulty of this control process. Falls are quite common also in older adults and in people with orthopedic or neurological disorders (Lord et al., 2001; WHO, 2007) and more importantly in these groups the consequences of falls are often severe (MacIntyre & Dewan, 2016; Talbot et al., 2005; Wenning et al., 1999).

From a mechanical perspective, it is not surprising that falls are common during walking. In human bipedal gait, the base of support is formed by those parts of the feet that are in contact with the floor. The base of support during walking is small, particularly in single stance. In addition, a large part of the total body mass is located high above the base of support. Consequently, even small deviations of the center of mass position can result in substantial gravitational moments that accelerate the center of mass out of the base of support. Both internal sources of noise (e.g. sensory noise and motor noise) and external perturbations (e.g. uneven terrain, gusts of wind) can cause deviations in center of mass position with respect to the base of support. Given that walking is inherently unstable, ongoing (intermittent or continuous) stabilization is needed, to avoid cumulative effects of small perturbations over time. When major perturbations occur, which are here defined as external mechanical events that disturb the relation between center of mass and base of support beyond the variance observed in unperturbed gait, the need for stabilizing control is evident.

Stabilization of gait can be achieved by passive and active mechanisms. Passive stabilization relies on the passive mechanical properties (stiffness, damping and inertia of the human body), whereas active

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Table of Contents Application Note And Stabilizing Feedback Loops In Today

1. Understanding the eBook Application Note And Stabilizing Feedback Loops In Today
 - The Rise of Digital Reading Application Note And Stabilizing Feedback Loops In Today
 - Advantages of eBooks Over Traditional Books
2. Identifying Application Note And Stabilizing Feedback Loops In Today
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Application Note And Stabilizing Feedback Loops In Today
 - User-Friendly Interface
4. Exploring eBook Recommendations from Application Note And Stabilizing Feedback Loops In Today
 - Personalized Recommendations
 - Application Note And Stabilizing Feedback Loops In Today User Reviews and Ratings

- Application Note And Stabilizing Feedback Loops In Today and Bestseller Lists
- 5. Accessing Application Note And Stabilizing Feedback Loops In Today Free and Paid eBooks
 - Application Note And Stabilizing Feedback Loops In Today Public Domain eBooks
 - Application Note And Stabilizing Feedback Loops In Today eBook Subscription Services
 - Application Note And Stabilizing Feedback Loops In Today Budget-Friendly Options
- 6. Navigating Application Note And Stabilizing Feedback Loops In Today eBook Formats
 - ePub, PDF, MOBI, and More
 - Application Note And Stabilizing Feedback Loops In Today Compatibility with Devices
 - Application Note And Stabilizing Feedback Loops In Today Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Application Note And Stabilizing Feedback Loops In Today
 - Highlighting and Note-Taking Application Note And Stabilizing Feedback Loops In Today
 - Interactive Elements Application Note And Stabilizing Feedback Loops In Today
- 8. Staying Engaged with Application Note And Stabilizing Feedback Loops In Today
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Application Note And Stabilizing Feedback Loops In Today
- 9. Balancing eBooks and Physical Books Application Note And Stabilizing Feedback Loops In Today
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Application Note And Stabilizing Feedback Loops In Today
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Application Note And Stabilizing Feedback Loops In Today
 - Setting Reading Goals Application Note And Stabilizing Feedback Loops In Today
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Application Note And Stabilizing Feedback Loops In Today
 - Fact-Checking eBook Content of Application Note And Stabilizing Feedback Loops In Today
 - Distinguishing Credible Sources

13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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