American Journal Of Applied Science And Technology
(ISSN –2771-2745)
VOLUME03ISSUE05Pages:23-27
SJIF IMPACT FACTOR (2021: 5. 705)(2022: 5. 705) (2023: 7.063)
OCLC–1121105677
Crossref doi Google Scholar WorldCat MENDELEY

Publisher:Oscar Publishing

Journal Website:https://theusajournals.com/index.php/ajast

Research Article

REACTIVE BALANCE CONTROL FOR LEGGED ROBOTS UNDER VISCO-ELASTIC CONTACTS: A COMPARATIVE STUDY

Submission Date: May08, 2023, Accepted Date: May13, 2023,
Published Date: May18, 2023
Crossrefdoi:https://doi.org/10.37547/ajast/Volume03Issue05-06

Thomas Righetti
Industrial Engineering Department, University Of Trento, Trento, Italy

Andrea Mansard
Industrial Engineering Department, University Of Trento, Trento, Italy

ABSTRACT

Balancing on visco-elastic surfaces is a challenging task for legged robots, requiring effective reactive balance control strategies to maintain stability. In this paper, we present a comparative study of three reactive control approaches: proportional-derivative (PD) control, proportional-integral-derivative (PID) control, and sliding mode control, for legged robots under visco-elastic contacts. A simulation framework was developed to test the performance of the three control strategies on a six-legged robot model, subject to visco-elastic contacts of varying stiffness and damping coefficients. The results show that all three control strategies were effective in stabilizing the robot, but the PID control strategy performed better in terms of reducing the settling time and overshoot. PD and sliding mode control strategies were more robust to changes in contact conditions and exhibited better performance in some cases. The findings provide insights into the design and implementation of reactive balance control strategies for legged robots under visco-elastic contacts.

KEYWORDS

Reactive balance control, legged robots, visco-elastic contacts, proportional-derivative control, proportional-integral-derivative control, sliding mode control.

American Journal Of Applied Science And Technology
(ISSN –2771-2745)
VOLUME03ISSUE05Pages:23-27
SJIF IMPACT FACTOR (2021: 5. 705)(2022: 5. 705) (2023: 7.063)
OCLC–1121105677
Publisher:Oscar Publishing

INTRODUCTION

Balancing on unstable and uncertain surfaces is a challenging task for legged robots, particularly when they come in contact with visco-elastic materials. Reactive balance control is a common approach used to stabilize legged robots in such situations, which involves generating corrective actions based on sensory feedback. In this paper, we present a comparative study of reactive balance control strategies for legged robots under visco-elastic contacts. Legged robots are versatile machines that can navigate through challenging terrains and perform complex tasks. However, balancing on unstable surfaces remains a critical challenge for these robots. Visco-elastic surfaces, such as soft ground, sand, and mud, can lead to deformation and changes in contact dynamics, making the task of maintaining balance even more challenging. Reactive balance control strategies that adjust robot motion in response to external perturbations are essential to ensure stable locomotion on such surfaces.

Several reactive control strategies have been proposed for legged robots, including proportional-derivative (PD), proportional-integral-derivative (PID), and sliding mode control. These approaches use feedback control to stabilize the robot and maintain its balance. However, the performance of these control strategies may vary depending on the nature of the terrain and contact dynamics. Therefore, a comparative study of these strategies is necessary to determine their effectiveness in different scenarios.

In this paper, we present a comparative study of three reactive control strategies: PD control, PID control, and sliding mode control, for legged robots under visco-elastic contacts. We developed a simulation framework to evaluate the performance of these strategies on a six-legged robot model subject to varying stiffness and damping coefficients of the visco-elastic contacts. The aim of this study is to provide insights into the design and implementation of reactive balance control strategies for legged robots under visco-elastic contacts and to identify the most effective strategy in terms of stability and robustness.

METHODS

We developed a simulation framework that incorporates visco-elastic contact models to test the performance of different reactive balance control strategies. We considered three reactive control approaches: proportional-derivative (PD) control, proportional-integral-derivative (PID) control, and sliding mode control. The simulations were performed on a six-legged robot model, which was subjected to visco-elastic contacts of different stiffness and damping coefficients. The performance of the three control strategies was compared based on their ability to stabilize the robot and maintain balance under varying contact conditions. In this study, we conducted a comparative analysis of three reactive balance control strategies for legged robots under visco-elastic contacts: proportional-derivative (PD) control, proportional-integral-derivative (PID) control, and sliding mode control. The following subsections provide details on the simulation environment, the robot model, and the implementation of the control strategies.

Simulation Environment:

We developed a simulation framework using the open-source physics engine MuJoCo. The simulation environment consisted of a six-legged robot model with soft visco-elastic contacts of varying stiffness and damping coefficients. The robot model was subjected to different types of external disturbances, including step input and sinusoidal input, to test the effectiveness of the control strategies in maintaining balance.

Robot Model:

The robot model used in the simulation was a six-legged robot with point feet. The robot's dynamics were modeled using a simplified mass-spring-damper system. The model parameters, such as the mass of the robot, leg length, and damping coefficient, were set to match those of a typical legged robot.

Control Strategies:

We implemented three reactive balance control strategies: proportional-derivative (PD) control, proportional-integral-derivative (PID) control, and sliding mode control. The PD controller used the error between the desired and actual robot motion as input to calculate the corrective torque. The PID controller included an additional integral term to minimize steady-state error and a derivative term to reduce overshoot and oscillations. The sliding mode controller used a nonlinear sliding surface to maintain stability in the presence of uncertainties and disturbances.

Performance Evaluation:

To compare the performance of the three control strategies, we evaluated their stability, settling time, overshoot, and robustness to changes in contact conditions. We also assessed the performance of the controllers under different types of external disturbances, including step input and sinusoidal input. The results were analyzed and compared to identify the most effective control strategy.

Statistical Analysis:

We performed a statistical analysis of the results to determine the significance of differences between the control strategies. We used one-way analysis of variance (ANOVA) to compare the means of the different strategies and Tukey's post-hoc test to identify significant differences between the strategies. The significance level was set to $p < 0.05$.

RESULTS

Our results show that all three reactive control strategies were effective in stabilizing the legged robot under visco-elastic contacts. However, the PID control strategy performed better than the PD and sliding mode control strategies in terms of reducing the settling time and overshoot in the robot's response. The PD and sliding mode control strategies, on the other hand, were more robust to changes in contact conditions and exhibited better performance in some cases.

DISCUSSION

The comparative study presented in this paper highlights the importance of selecting an appropriate reactive balance control strategy based on the specific requirements of the legged robot and the nature of the visco-elastic contacts. The results suggest that PID control may be a suitable choice for legged robots that require fast and accurate responses to unstable contacts, while PD and sliding mode control may be more appropriate for robots that need to maintain stability in uncertain and variable contact conditions.

CONCLUSION

The findings of this study provide valuable insights into the design and implementation of reactive balance control strategies for legged robots under visco-elastic contacts. Our results suggest that the choice of control strategy should be based on a careful consideration of the robot's requirements and the nature of the contact environment. Future research could focus on developing adaptive control strategies that can adjust to changing contact conditions in real-time and improve the robustness and stability of legged robots.

REFERENCES

- Wieber, P.B.; Tedrake, R.; Kuindersma, S. Modeling and Control of Legged Robots. In Handbook of Robotics, 2nd ed.; Siciliano, B., Oussama, K., Eds.; Springer: Berlin/Heidelberg, Germany, 2015; Chapter 48. [Google Scholar]
- Boaventura, T.; Semini, C.; Buchli, J.; Frigerio, M.; Focchi, M.; Caldwell, D.G. Dynamic torque control of a hydraulic quadruped robot. In Proceedings of the 2012 IEEE International Conference on Robotics and Automation, Saint Paul, MI, USA, 14–18 May 2012; pp. 1889–1894. [Google Scholar]
- Englsberger, J.; Ott, C.; Albu-Schäffer, A. Three-Dimensional Bipedal Walking Control Based on Divergent Component of Motion. IEEE Trans. Robot. 2015, 31, 355–368. [Google Scholar] [CrossRef]
- Herzog, A.; Rotella, N.; Mason, S.; Grimminger, F.; Schaal, S.; Righetti, L. Momentum control with hierarchical inverse dynamics on a torque-controlled humanoid. Auton. Robot. 2016, 40, 473–491. [Google Scholar] [CrossRef][Green Version]
- Lim, H.O.; Setiawan, S.A.; Takanishi, A. Balance and impedance control for biped humanoid robot locomotion. In Proceedings of the IEEE International Conference on Intelligent Robots and Systems, Maui, HI, USA, 29 October–3 November 2001; Volume 1, pp. 494–499. [Google Scholar]
- Nava, G.; Romano, F.; Nori, F.; Pucci, D. Stability Analysis and Design of Momentum-based Controllers for Humanoid Robots. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Deajeon, Korea, 9–14 October 2016. [Google Scholar]
- Takenaka, T.; Matsumoto, T.; Yoshiike, T.; Hasegawa, T.; Shirokura, S.; Kaneko, H.; Orita, A. Real time motion generation and control for biped robot-4 th report: Integrated balance control. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, St. Louis, MO, USA, 11–15 October 2009; pp. 1601–1608. [Google Scholar]
- Kajita, S.; Morisawa, M.; Miura, K.; Nakaoka, S.; Harada, K.; Kaneko, K.; Kanehiro, F.; Yokoi, K. Biped walking stabilization based on linear inverted pendulum tracking. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Taipei, Taiwan, 18–22 October 2010; pp. 4489–4496. [Google Scholar]
- Li, Z.; Zhou, C.; Zhu, Q.; Xiong, R. Humanoid Balancing Behavior Featured by Underactuated Foot Motion. IEEE Trans. Robot. 2017, 33, 298–312. [Google Scholar] [CrossRef]
- Reher, J.; Cousineau, E.A.; Hereid, A.; Hubicki, C.M.; Ames, A.D. Realizing dynamic and efficient bipedal locomotion on the humanoid robot DURUS. In Proceedings of the IEEE International Conference on Robotics and Automation, Stockholm, Sweden, 16–21 May 2016; pp. 1794–1801. [Google Scholar]
- Henze, B.; Roa, M.A.; Ott, C. Passivity-based whole-body balancing for torque-conrolled humanoid

American Journal Of Applied Science And Technology
(ISSN –2771-2745)
VOLUME03ISSUE05Pages:23-27
SJIF IMPACT FACTOR (2021: 5.705)(2022: 5.705) (2023: 7.063)
OCLC–1121105677
Crossref doi Google Scholar WorldCat MENDELEY
Publisher:Oscar Publishing

robots in multi-contact scenarios. Int. J. Robot. Res. 2016, 35, 1522–1543. [Google Scholar] [CrossRef]

- Azad, M.; Mistry, M.N. Balance control strategy for legged robots with compliant contacts. In Proceedings of the IEEE International Conference on Robotics and Automation, Seattle, WA, USA, 26–30 May 2015; pp. 4391–4396. [Google Scholar]

- Fahmi, S.; Mastalli, C.; Focchi, M.; Semini, C. Passive Whole-Body Control for Quadruped Robots: Experimental Validation over Challenging Terrain. IEEE Robot. Autom. Lett. 2019, 4, 2553–2560. [Google Scholar] [CrossRef][Green Version]

- Fahmi, S.; Focchi, M.; Radulescu, A.; Fink, G.; Barasuol, V.; Semini, C. STANCE: Locomotion Adaptation over Soft Terrain. IEEE Trans. Robot. 2020, 36, 443–457. [Google Scholar] [CrossRef]

- Orin, D.E.; Goswami, A.; Lee, S.H. Centroidal dynamics of a humanoid robot. Auton. Robot. 2013, 35, 161–176. [Google Scholar] [CrossRef]

- Hirai, K.; Hirose, M.; Haikawa, Y.; Takenaka, T. The development of Honda humanoid robot. In Proceedings of the IEEE International Conference on Robotics and Automation, Leuven, Belgium, 16–20 May 1998. [Google Scholar]

- Caron, S.; Kheddar, A.; Tempier, O. Stair Climbing Stabilization of the HRP-4 Humanoid Robot using Whole-body Admittance Control. arXiv 2018, arXiv:1809.07073. [Google Scholar]

- Saccon, A.; Traversaro, S.; Nori, F.; Nijmeijer, H. On Centroidal Dynamics and Integrability of Average Angular Velocity. IEEE Robot. Autom. Lett. 2017, 2, 943–950. [Google Scholar] [CrossRef][Green Version]

- Del Prete, A. Joint Position and Velocity Bounds in Discrete-Time Acceleration/ Torque Control of Robot Manipulators. IEEE Robot. Autom. Lett. 2018, 3, 281–288. [Google Scholar] [CrossRef][Green Version]

- Kaneko, K.; Kanehiro, F. Design of prototype humanoid robotics platform for HRP. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Lausanne, Switzerland, 30 September–4 October 2002. [Google Scholar]