



BIPEDAL HUMANIOD ROBOTIC LEG

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Abstract : This literature review presents a in-depth examination of the development and research work on the design and control of bipedal humanoid robotic legs. It discusses numerous mechanical configurations, actuation techniques, and regulated strategies developed during the last decades to simulate human walking. The review emphasizes key aspects like kinematic and dynamic modeling, trajectory planning, balance control, and sensory feedback integration for adaptive movement. In addition, it considers the application of artificial intelligence and machine learning for improving gait stability and adaptability on varied terrain. Based on the evaluation of different robotic systems and experimental results, the paper stresses the ongoing challenges of realizing efficient, stable, and energy-saving bipedal locomotion. This review is intended to establish the basis for understanding for researchers and engineers, recognizing areas left open by previous literature and suggesting directions for future exploration in the design of humanoid robotic legs.

IndexTerms - Humanoid robotic leg, Bipedal locomotion, Gait control, Kinematic modeling, Dynamic modeling, Actuation system, Sensory feedback, Balance and stability

I. INTRODUCTION

Bipedal humanoid robotic legs are at the forefront of technological innovation, with an emphasis on developing robots that are capable of mimicking human-like movement, balance, and flexibility. By mimicking the complex configuration and movement of human legs, these robots have the ability to traverse difficult environments, interact with humans in a more natural manner, and execute agility and precision-based tasks. Applications of their kind are extensive, ranging from prosthetics and exoskeletons to service robots, search and rescue missions, rehabilitation, and human-robot interaction, each of which is potentially designed to enhance mobility and offer support. However, the creation of such robots brings with it substantial challenges in terms of sustaining stable balance, achieving efficient walking gaits, responding to varied environments, and realizing successful control mechanisms. This needs to be done while incorporating cutting-edge sensors and AI algorithms, and also meeting concerns regarding energy efficiency and safety. This area draws on innovations in robotics, artificial intelligence, machine learning, materials science, and biomechanics to increase the capabilities of robots, hence enhancing human-robot interaction and flexibility to different environments. As research continues to expand, bipedal humanoid robots are set to revolutionize various fields and enhance the lives of individuals with mobility impairments, as well as deepening our knowledge of human movement and robotics.

II. Literature Survey

The research paper by Chih-Cheng Liu et al. [1], explores a model predictive control (MPC) approach that seeks to enhance walking stability in bipedal robots on uneven terrain. The authors created a dynamic control system that integrates terrain data with predictive modeling to enhance balance and flexibility in the robot. With MPC, the system can predict future environmental conditions and adjust foot placement and body posture in real time, thus offering smoother and more stable motion on uneven or sloping terrain. Simulation and empirical testing confirm the effectiveness of the strategy in maintaining stability in the presence of difficult walking conditions and highlight its promising capabilities for robotic mobility improvement in complex environments.

The study by Nisal Perera et al. [2], introduces StaccaToe, a new single-leg robot that captures the agility and structure of the human leg. The all-electric robot contains two cutting-edge bioinspired elements: an actuated toe and a co-actuation mechanism, which enable it to generate large ground reaction forces and remain balanced without the use of energy storage elements such as springs or hydraulics. From the HyperLeg platform, the researchers have developed a robust framework utilizing innovative link designs, custom-made electronics, and an optimal control strategy. StaccaToe has been effectively demonstrated through hardware testing, exhibiting a balanced tip-toe posture and impressive jumping motions, thereby presenting its precision in control and dynamic performance.

The research by Emanuel Muntean and Monica Leba [3], describes control of motion that mimics human locomotion. It uses inertial measurement units (IMUs) to track the orientation and movement of the robot lower limb with high accuracy. Motor control using PCA9685, a 16-channel 12-bit PWM servo driver, commands servo motors to achieve precise smooth leg movements. The control algorithm runs on an Arduino Uno and Arduino Nano microcontroller. With the aid of three servo motors, the robotic leg could

simulate realistically agile motions. The system aims to enhance stability and application so that the robot can walk across an array of terrains by imitating human leg movements. This method led to bettering robot's equilibrium ability and performance in coordinated walking maneuvers through the fusion of IMU data and motor control via Arduino platforms.

The study by Peng Zhang et al. [4], evaluates a gait control framework with multiple dynamic movement primitives to allow the system to learn a continuous, smooth gait for stair climbing. This new way of controlling exoskeletons allows them to learn and execute the continuous, and coordinated body motions it faces for stair movement or approach by consistently adjusting its gait as it senses the stair location and interaction from the user and can better handle the complexity of human biomechanics. With running multiple simulations, then also real-world experiments, the authors could verify that the CDP method improved the exoskeletons stability, adaptability, and efficiency while climbing up or down stairs. Their study improved a robotic walking exoskeletons functioning toward achieving more advanced, human-like motions in wearable robotic systems for rehabilitation and assistance.

The study by Rada Chuengpichanwanich et al. [5], explores the actions of the legs when people walk, to improve stability, through a kinematic model. This attention to the coordination of joint angles and the attributes of spatial trajectories were woven within the framework to encourage dynamic and stable bipedal movement by allowing for precision in the control of human joints while modifying leg actions for real-time performance. By conducting various performed simulations and real experiments, the authors were successfully able to illustrate that the kinematic control strategy not only resulted in only reduced instability in the production of movement but also created more effective means of bipedal locomotion.

The paper by Youngwoo Sim and Joao Ramos [6], provides a learning adaptive model for flexible behavior strategies for exoskeletons, which addresses individual user differences and varying environmental conditions. Recognizing that all users and terrains vary, the authors propose an alternative way to achieve experience-based learning that allows for an adaptation of exoskeleton behavior without as much data to adjust to user and environment dynamics. The framework uses policy adaptation methods that promote broad applicability across number of gait types, body dynamics, and external factors. Motivated by prior experience rather than just current data, the authors' approach enhances learning speed to minimize the time span users would take to develop proficiency while maintaining consistent performance. The experiments included simulations and hardware experimentation that shows how the system had performed rapid adaptation to new users and environmental conditions, stability, and safety are not further compromised through this speed of adaptability, thus advancing toward an intelligent exoskeleton that is capable of real-time adaptability and individualized assistance.

The research by Ahmadreza Shahrokhshahi et al. [7], investigates the application of deep convolutional neural networks (CNNs) for the classification of walking environments relevant to assistive robotic devices. Such classification is critical for enabling intelligent transitions of control when walking with these devices, particularly across different terrains (e.g. stairs, ramps, or an uneven surface). Researchers designed a computer vision system utilizing wearable cameras and video data collected in the environment to identify motions in real-time that were subsequently used to train a deep CNN model for automatic classification of different walking environments. Using video data to predict changes in the terrain allows the prosthesis or exoskeleton to utilize control strategies preemptively. The results indicated good accuracy of classification and robust performance in different environments which supports the argument that deep learning could be a tool to create a more intelligent, environmental awareness in assistive robotics.

The study by Brokoslaw Laschowski et al. [8], presents the Tello Leg, a new legged platform for robotics to study and define basic design principles and performance metrics applicable to dynamic humanoid robots. The authors seek to improve performance through the mechanical design and actuation to perform rapidly, nimbly, and statically. The findings, especially the comparisons of important design characteristics of legged robots, such as weight distribution, joint configuration, and actuator, were assessed to determine their performance in running, jumping, and dynamic balancing. The Tello Leg serves as the mode of the experiment, used to validate theoretical models and design principles. Using both simulations and physical experiments, the paper demonstrates that the Tello Leg is appropriately tuned to perform dynamic motions, with mechanical performance considerations for efficiency and durability.

The study by Ke Wang et al. [9], describes SLIDER, introduces bipedal walking robot that occupies a unique position for its light-weight, knee-less structure and low-cost platform. The goals of the SLIDER project are to reduce the mechanical complexity generally found with bipedal robots, while still achieving effective and stable walking. The researchers advocate for a straight-legged walking design that removes knee joints combined with sophisticated controls to allow walking. The use of linear actuators and light-weight materials has enabled SLIDER to be up to this point, a low-cost and energy-efficient platform. An appropriate gait control system was developed according to its knee-less walking model and enables stable walking on flat ground. In preliminary experiments, results show that SLIDER was able to reliably achieve bipedal walking with minimal hardware, demonstrating that low-cost and simpler robots can provide a stable walking mechanism and functional performance.

The study by Kohei Kimura et al. [10], present a new innovative approach for bipedal robot locomotion, utilizing a passive wheel system and not the traditional swing-leg approach. The primary goal of this study is to examine and reduce the chance of falls, improving the robot's stability margin. The authors provide a suggested overall approach enabling the robot to traverse various terrains and adapt to changes in objectives while maintaining a state of stability. The results of the study demonstrate improved stability and smoother and more reliable locomotion using passive wheeled locomotion, compared to methods where traditional bipedal robots are highly unstable, are less resilient, or they encounter differing, dynamic environments.

The study by Thiago Tonaco et al. [11], investigates the mechanical design process of a humanoid robot leg with efficient and human-like movement. The authors present a systematic design approach to design the structure of the leg that includes the configuration of joints, degrees of freedom, selection of actuators that representative biomechanics of human movement patterns. There is emphasis in modularity, balance, and robustness in terms of planning but also practicality in terms of weight, size, and

consumption of energy as it relates to the physical restrictions of a humanoid robot. The authors utilized simulation tools to assess various design alternatives when designing the structure of the leg as well as the performance metrics of movement such as range of motion, stability, and energy efficiency.

The paper Janos Szots et al. [12], describes the creation of a low-cost bipedal robot focusing on simplicity, cost-effectiveness and effective walking controls. The authors provided a description of the mechanical design with light materials and relatively few parts, which could expedite manufacturing and reduce the cost to develop. While there were also designs for a control system, the research importantly will discuss the emphasis to keep walking stable using simple sensors and actuators. In that context the main part of the research is to study a control system that combines gait pattern generation in response to simple capabilities and retains balance about stability for a platform with constrained capabilities. The performance of the locomotion was successfully stable enough to observe simple target motions, leading toward educational purposes and initial robotic research.

III. Problem Identification

The main challenge in designing a robotic leg is achieving a graceful balance among mechanical strength, flexibility, and weight while also ensuring effective, stable, and adaptable movement. Traditional robotic systems often struggle to mimic the subtle motions of human legs. And achieve precise movement control of the robotic leg.

IV. Conclusion

This survey explores recent developments in the bipedal and legged robotics, focusing on control methodologies, mechanical design, and integration of sensors. Present-day research tries to establish stability in robotics, enhance its adaptability to uneven terrains, and conserve energy. Model Predictive Control and reinforcement learning help robots execute motion-related adjustments in real-time. Mechanical design changes incorporating lightweight structures and knee-less configurations offer slight improvements to the balance and agility while reducing weight and complexity. Real-time sensor feedback through the use of IMUs and vision is described as supporting viable interactions with the environment. This is particularly significant in assistive devices like exoskeletons and prosthetic legs that have to accommodate diverse users and environments. Many designs also strive to be low-cost and easy to build so that such manifestations of robotics find their way into rehabilitation, education, and personal mobility usage. Legged robotics are moving toward building intelligent, stable systems capable of operating in the real world, and walking, adapting, and assisting robots-human like-will come into existence through smart controls, efficient design, and real-time sensing.

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