International Journal of Analytical, Experimental and Finite Element Analysis
Volume 11, Issue 1, March 2024, pp 25-31
https://doi.org/10.26706/ijaefea.1.11.20240305

Design and Fabrication of Quadruped Robot

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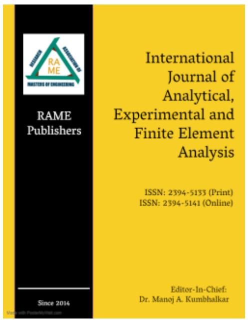
Abstract: One of the challenges facing while navigating a mobile robot over different terrains is the inability of the robot to adapt to different terrains. Most of the existing designs of the robots are designed for navigating on a specific terrain, so it is only applicable to a dedicated application. A single multi-purpose robot is cost-effective than multiple dedicated robots. To address the above-mentioned problems an innovative design is proposed termed as multi-terrain multi-utility robot. This paper describes the design and analysis of and vehicle with a wall maneuvering capability. Its applications include search and rescue, mapping, surveillance and military purposes.

Keywords: Quadruped Robot, Leged Robot, Theo-Jansen Mechanism.



RAME
Publishers

International
Journal of
Analytical,
Experimental and
Finite Element
Analysis

ISSN: 2394-5133 (Print)
ISSN: 2394-5141 (Online)

Editor-In-Chief:
Dr. Manoj A. Kumbhalkar

Since 2014

Article – Peer Reviewed
Received: 10 Jan 2024
Accepted: 5 March 2024
Published: 30 March 2024

Cite this article: Sangam Rane, Pravinkumar Yadav, Vikrant Chaturvedi, Satyaprakash Chaudhary, Vivek Tambe, "Design and Fabrication of Quadruped Robot", *International Journal of Analytical, Experimental and Finite Element Analysis*, RAME Publishers, vol. 11, issue 1, pp. 25-31, 2024.
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1. Introduction

The last three decades, the mobile robot has made much attention because of exploring in the complex environment, space, rescue operation, accomplishing a task without human effort, etc. The mobile robot can be broadly classified into three categories; wheeled robot, tracked robot, and legged robot [1]. The robot locomotion system is an essential characteristic of mobile design, and it depends not only on working space but also on a technical measure like maneuverability, controllability, terrain condition, efficiency, and stability [16]. Though wheeled and tracked robots can work in plane terrain, but most of them couldn't work in cluttered terrain, complex and hazardous environments [2].

The legged robot has more potential to roam almost all the earth surfaces in different terrains, just like the human and an animal [3]. The quadruped robots are the best choice among all legged robots related to mobility and stability [17]. Though wheeled and tracked robots can work in plane terrain, but most of them couldn't work in cluttered terrain, complex and hazardous environments [4]. The legged robot has more potential to roam almost all the earth surfaces in different terrains, just like the human and an animal, The quadruped robots are the best choice among all legged robots related to mobility and stability of locomotion [5]. The four legs of the robot are easily controlled, designed, and maintained as compared to two or six legs. Mountain goats bound up steep cliffs, camels pace across shifting sands, gazelles leap huge obstacles [6]. Elephants amble through dense jungles while carrying enormous loads, spiders crawl up walls, and cockroaches, virtually indestructible, explore the entire planet [7].

2. Literature Review

This paper contributes to the research field of legged locomotion by introducing a light-weight, affordable yet comprehensive quadruped robot mechanism [8]. It provides novice researchers in the field a resource for studying more advanced problems, such as multi-body dynamics, nonlinear foot-ground contact modeling, gait path planning and attitude control, etc., at lower costs. By a combination of appropriate foot-ground contact modeling and control methodologies, this study uses rudder servos for actuating associated leg joints to control the gait patterns and roll-pitch attitude of the robot on uneven terrain [9]. While the joint angle tracking accuracies may not be ultra- high, especially under large environment disturbances and/or at high speeds, the proposed design further improves the accessibility and practicality of low-cost quadruped robots with various functionalities [10].

In this research, the foot fall point control based on the ZMP method in the X-Y plane, foot trajectory planning based on the MPC method in the X-Z plane, and inverse kinematics motor angle calculation is systematically integrated. Then, the trajectory planning and foot end fall control of the trot gait of the small robot are simulated and verified by experiments [11].

This paper introduces a stratified framework in which the upper-level planning layer furnishes motion parameters to the lower-level control layer [12]. Following this, the lower-level control layer computes the relevant motor torque predicated on the input parameters, thereby attaining meticulous robot control [18]. This methodology efficiently diminishes the exploration range at the upper level, thereby expediting real-time adaptations and revisions to accommodate alterations and uncertainties in the system. Consequently, it amplifies the training efficiency and bolsters the resilience of the system [13].

To establish the forward kinematics of the quadruped robot, this paper employs the D-H modeling method, enabling the derivation of the Jacobian matrix and the analysis of the simplified dynamic model [19]. The proposed HRL framework consists of a high-level planner that utilizes the Deep Deterministic Policy Gradient (DDPG) method to generate the optimal motion parameters for the robot [14]. At the lower level, the controller employs the MPC method and composite trajectory planning method to address the foot-end forces during the support and swing phases and calculate the output torque for each joint motor. The motion performance of both the DDPG method and the proposed hierarchical method during training is analyzed using Matlab/Simulink software [15]. This analysis serves to validate the effectiveness of the hierarchical deep reinforcement learning (DRL) model and acts as a reference for subsequent motor selection and optimization of actual prototypes [20].

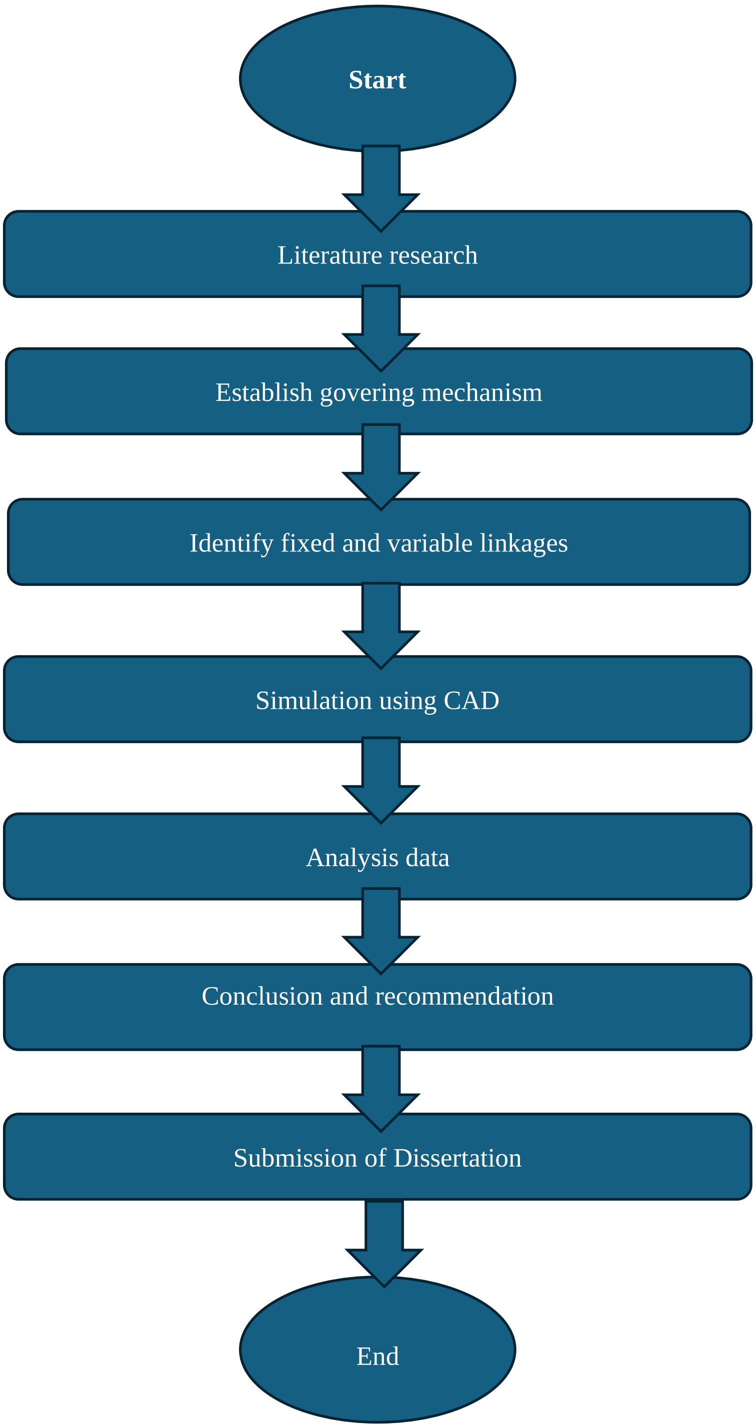
The research gap of the above survey is the Quadruped Robot have a Load carrying capacity of about 5-6 kg, which able to walk on rough terrain. Understanding the Leg Mechanism, which works on Theo-Jansen Mechanism.

3. Problem Identification

Although their motion usually takes place in known, controlled environments like a factory department stores, and so on other occasions they have to move in dangerous, inhospitable, and extreme environments. There are some instances whereby wheeled robots are not the best choice. Wheeled robots cannot navigate well over obstacles, and this is the main drawback depending on terrain. One of the most fundamental problems is how to establish the coordinated leg motions that make the robot walk. These coordinated motions, which support and propel the walking robot or animal, are called a gait. To achieve efficiency, mobile robots are often used to move objects from one place to another. This is a crucial application of robots in office, military, hospital and factory floor applications. The first issue affecting mobile robots is locomotion. Although their motion usually takes place in known, controlled environments like a factory, department stores, and so on, on other occasions they have to move in dangerous, in hospitable, and extreme environments.

4. Methodology

The methodology for this study begins with an extensive literature review to establish a solid theoretical foundation, identifying existing research, and understanding relevant concepts and methodologies. Following this, a governing mechanism is established to outline the framework for the study. Fixed and variable linkages are identified, defining the relationships and interactions among different elements within the system. The next step involves the use of Computer-Aided Design (CAD) tools to simulate the proposed model, which allows for visualizing and testing the linkages and their effects. Once the simulations are complete, data is gathered and analyzed to evaluate the performance of the system, drawing conclusions based on the observed outcomes. Finally, recommendations are made based on the analysis, and the dissertation is written and submitted for review. This structured approach ensures a comprehensive investigation, leading to meaningful insights and valid conclusions.



5. CAD Model of Quadruped Robot

The start of the CAD model for the quadruped robot involves the design of the robot's frame, which functions as the central body, offering support and accommodation for essential components such motors, batteries, and control units. Each leg of the quadruped is composed of many segments, usually an upper leg, lower leg, and foot, which are joined together by joints. The joints are fitted with bearings and shafts to facilitate seamless motion, powered by motors strategically placed at each joint, therefore guaranteeing correct alignment and operational effectiveness. Linkages, constructed from mild steel, are specifically engineered to interface the motor with the leg segments, therefore guaranteeing optimal transmission of motion. The design integrates gears that are precisely aligned with the motor shafts to provide precise leg movements. The robot's electronic components, including the battery, are contained within the main body structure in specifically assigned compartments. Following the assembly of all components, the CAD program is utilized to produce several perspectives of the robot, encompassing front, side, top, and isometric views. The provision of these perspectives enables a thorough visual comprehension of the robot's design and functionality from several perspectives, therefore assuring the model's structural integrity and operational feasibility.

The below table summarizes the materials, their specifications, quantities, and prices for easy reference.

Table 1. Bill of Material

Sr No.	ITEM	SPECIFICATION	QTY	PRICE
1	Motor	24V 250W	1	3200
2	Battery	12V 7Ah	2	2000
3	Bearing Housing	Dia 16mm	4	1500
4	Gear	Dia 100mm Module 2mm	3	1500
5	Shafts	Dia 16mm Length 1.5 ft	2	500
6	Wood Material	Area 200m^2	1	500
7	Mild Steel Linkages	Various Length	32	1000

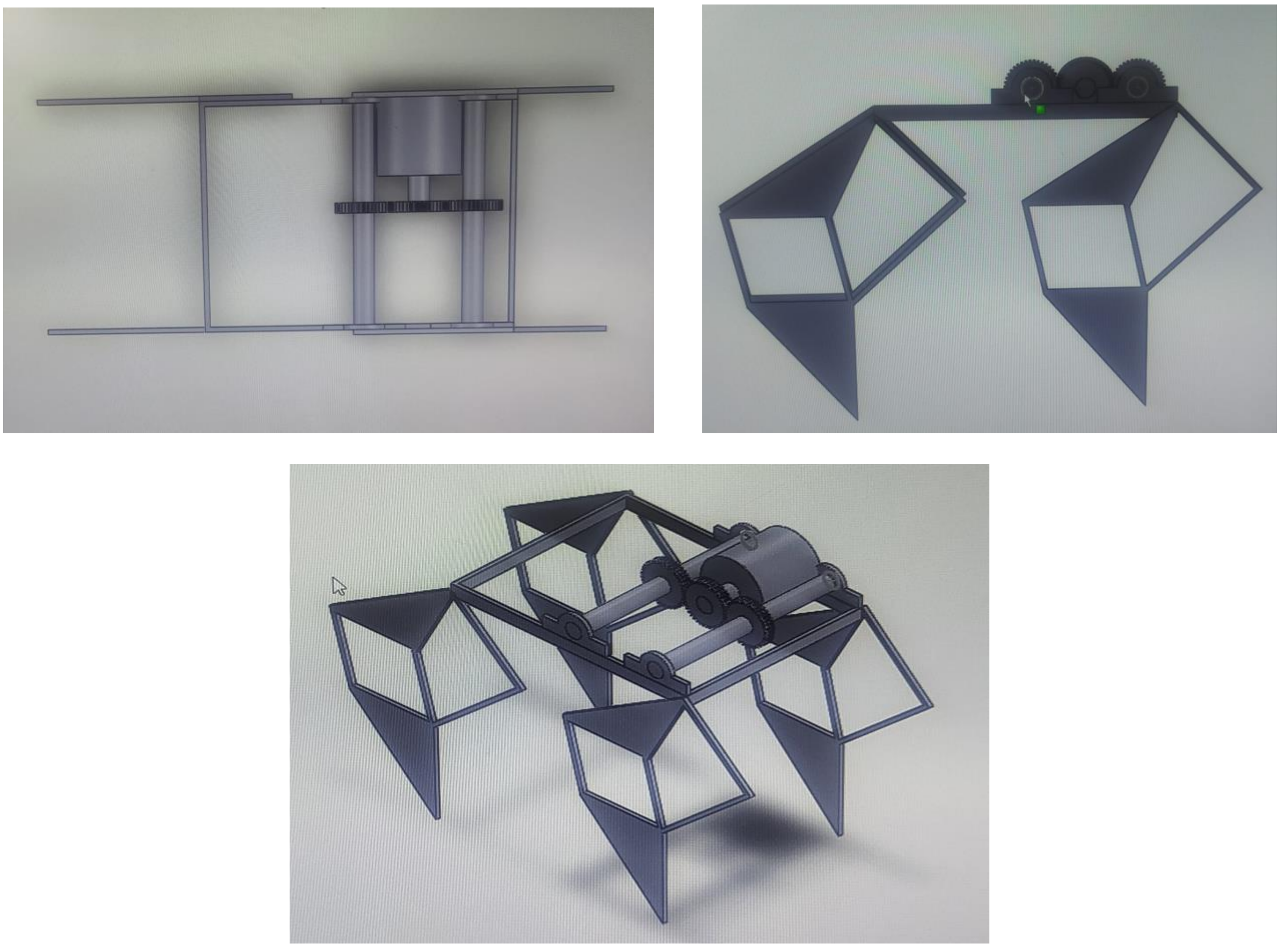


Figure 1. CAD Model of Quadruped Robot with all views

6. Design of Quadruped Robot

Below are the technical specifications, followed by the statements with formulas used for calculations, and the results in tabular form.

Table 2. Technical Specifications

Component	**Specification**
MS Square Pipe Length	1.8 m
MS Square Pipe Thickness	0.005 m
MS Square Pipe Width	0.18 m
MS Square Pipe Density	7850 kg/m³
MS Rod Diameter (r)	4 mm
MS Rod Length (h)	1.5 m
Motor Power	24V 250W
Motor RPM (NM)	300 rpm
Gear Diameter (DG)	100 mm
Number of Gear Teeth	50
Link Diameter (DL)	75 mm
Load Capacity	4.2 kg
Total Mass of Robot	20 kg
Battery Voltage	12V (2 in series for 24V)
Battery Capacity	7Ah each

(a) Mass of MS Square Pipe

$$Mass = l \times t \times w \times density$$

(b) Mass of MS Rod

$$\text{Volume} = \pi\, r^2\, h$$

$$\text{Mass} = \text{Volume} \times \text{density}$$

(c) Total Mass

$$\text{Total Mass} = \text{Mass of pipe} + \text{Mass of rod} + \text{Mass of other components}$$

(d) Force on the Robot

$$\text{Force} = \text{Total mass} \times g$$

Where $g=9.81\ m/s^2$ is the acceleration due to gravity.

(e) Gear Module and Pitch

$$\text{Module} = \frac{D}{\text{Number of teeth}}$$

$$\text{Pitch} = \frac{\pi D}{\text{Number of teeth}}$$

(f) Link RPM (NL)

$$\frac{NG}{NL} = \frac{DL}{DG}$$

(g) Velocity of the Link

$$V = \frac{\pi d N}{60}$$

(h) Power of the Motor

$$P = F \times V$$

(i) Battery Capacity (Ah)

$$\text{Wh} = \text{Ah} \times V$$

$$\text{Ah} = \frac{P \times t}{V}$$

(j) Torque of the Motor

$$T = \frac{P \times 60}{2\pi N}$$

This table provides a concise overview of the results obtained from the technical calculations, helping to validate the design and ensure that the components selected meet the robot's operational requirements.

Table 3. Results obtained from the technical calculations

Component	**Result**
Mass of MS Square Pipe	12.717 kg
Mass of MS Rod	0.59 kg
Total Mass	20 kg
Force on Robot	196.2 N
Gear Module	2 mm
Pitch of Gear	6.28 mm
Link RPM (NL)	312 rpm
Velocity of Link	1.24 m/s
Power of Motor	243 W
Battery Capacity	5.2 Ah
Torque of Motor	8 Nm

Quadrupedal robots, designed to carry additional payloads ranging from 5 to 8 kg, demonstrate enhanced load-bearing capabilities while traversing various terrains. This increased capacity expands their utility in tasks requiring transportation of equipment or supplies over rugged or uneven surfaces, such as in field reconnaissance, logistics support, or disaster relief operations. Additionally, advancements in materials and control systems contribute to improved efficiency and stability, enabling these robots to navigate challenging environments while carrying heavier load.

7. Conclusion

In this study, the design and analysis of a quadruped robot were successfully conducted, calculating critical parameters like mass, force, gear specifications, motor power, battery capacity, and torque. The total mass of the robot was determined to be 20 kg, providing sufficient stability, while the force exerted by the robot was 196.2 N. The gear module and pitch were calculated to be 2 mm and 6.28 mm, respectively, ensuring proper gear engagement. The output link RPM was 312, resulting in a link velocity of 1.24 m/s, and the selected motor, rated at 250 W, was capable of delivering 8 Nm torque, allowing efficient operation.

The broader conclusion on quadruped robots highlights their advantages, including stability, maneuverability in rough terrain, and promising applications in fields like search and rescue, exploration, agriculture, construction, and disaster response. Despite these benefits, challenges such as control algorithms, power efficiency, and scalability across different environments persist. Ongoing research and development are essential to overcoming these obstacles.

Quadruped robots demonstrate significant potential, particularly in scenarios where traditional wheeled or tracked robots face limitations. With continued technological innovation, quadruped robots are poised to play an increasingly important role across industries, augmenting human capabilities and addressing complex challenges. This analysis provides a strong foundation for the practical deployment of quadruped robots in real-world applications.

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