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Research Article

Spider Bot – A Quadruped Robot for Data Gathering

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Abstract

Humans could not traverse to every point on the surface, yet they still require information about such locations, such as in the fields of astronomy, geology, the military, etc. As a result, researchers have designed cutting-edge technologies have enabled data gathering from locations where humans are unable to travel. Our research is one of these technologies, and it is extremely useful in a variety of applications, including remote sensing and evacuation. A quadruped robot bio inspired from the spider structure with 3 Degree of Freedom for each leg is fabricated. Structure is so chosen that offers a good manoeuvrability on uneven surfaces thus offering it a biological resemblance of a spider. searching for survivors in war zones, examining precarious structures after natural disasters like earthquakes, tsunamis, or volcanic eruptions, taking pictures of dangerous wildlife like lions and tigers, etc. are all examples of exploring risky locations for humans for which the proposed model offers a solution.

Keywords: Quadruped robot, Spider bot, Bio inspired design, Biomimetics, Robot training.

1. Introduction

Exploring the earth's environment can be dangerous and difficult in some places, for example, in hostile environments and inhospitable terrains that are difficult to reach with regular vehicles. After critically evaluating and interpreting numerous robot architectures, a quadruped (spider) robot design was adopted due to the spider's natural movement and its capacity to navigate through terrain regardless of its exterior. This design gives the Spider Robot legs the same range of motion thus mimicking a biological spider. The Spider Robot could be used to examine hazardous regions for people, investigate conflict zones, check for precarious and erotic structures after earthquakes, and search for and deactivate munitions like mine fields.

The study done by Wenkai Huang et al. [1] offered a novel three-dimensional flexible construction. This passive compliant three-dimensional flexibility minimizes the robot's weight and complexity. A side impact experiment validates the robot's anti-impact capability. The hexapod bionic spider robot's structural design [2] is the primary emphasis of this research, which also optimizes and enhances the original model. The body of the spider-like robot is created from a bionics perspective in order to meet the needs of the hexapod bionic spider robot for flexibility and stability. The initial model is improved by studying the structural proportions of the robot's legs as well as the original design flaws. A lightweight, inexpensive, yet complete quadruped robot system [3], which advances the study of legged movement. It gives beginning researchers in the field a tool for exploring more complex issues, such multi-body dynamics, nonlinear foot-ground contact modelling, gait route planning, attitude control, etc., for less money.

The key features [4] and highlights of the HyQ2Max3 design, which primarily draws from HyQ's morphology, torque control, and hydraulic actuation innovations. The main contributions of this paper include a novel design of an agile quadruped robot capable of trotting or crawling over flat or uneven terrain, balancing, and self-righting; a detailed method to identify appropriate hydraulic cylinder/valve properties and linkage parameters with a focus on maximizing the actuator areas and to the best of the authors' knowledge, the most thorough review of hydraulic quadruped robots. An inverse kinematics program [5] of a quadruped robot with three degrees of freedom on each leg, inverse kinematics solutions are offered in this paper. To calculate the forward kinematic, one uses the Denavit-Hartenberg (D-H) technique. The geometrical and mathematical approaches' inverse kinematic equations are programmed in MATLAB. The development of MiniHyQ robot [6] is a significant step forward in miniature hydraulics in robotics. We demonstrated the development of lightweight hydraulic actuated quadruped. We also show novel knee joint: despite its higher complexity, the isogram mechanism is superior to the traditional design, because its many kinematic parameters can be fine-tuned to achieve an optimal torque profile.

The main goal of the research [7] was to create a quadruped that operates well in challenging environments and uneven terrain where human assistance is challenging or impossible. The methods used to optimize legged robots [8], including a description of the structural parameters, adhering to good mechanical project regulations, maximizing weight, power, and energy indices, as well as additional approaches like the use of evolutionary measurement to mimic the biological characteristics of animals. Methodology and operation of the "SPY SPIDER," [9] an eight-legged waking robot looks like a spider and may be securely used for spying. This project does not need microprocessor control or a large number of actuator mechanisms in order to walk over curbs, climb stairs, or enter spaces that are now inaccessible to wheels. PADWQ dynamic quadruped robot [10], an open-source dynamic quadruped robot with 12 torque controlled

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quasi direct drive joints and high control bandwidth, an onboard depth sensor, and a computer with GPU that enables highly dynamic locomotion over unsteady terrains. A quadruped robot's leg structure [11] was created via mechanism synthesis in order to provide a system for the intricate control of a quadruped robot.

A comprehensive understanding [12] of the quadruped robots has been provided in a concise way while synthesizing the available facts. In this field, locomotion, structural design, gait analysis, and actuator are the primary focal areas. MIT researchers have developed a set of modules and a related integration architecture [13] that enable dynamic, quick exploration of uncharted and unstructured areas. The gap between the hardware and control advancements to date will be filled by these low-level autonomy modules and perceptual integration. Using Intel RealSense for capturing the dynamic motion of the MIT Mini-Cheetah, as well as algorithms for real-time obstacle avoidance in highly irregular terrain. The work [14] presents the design of a parallel quadrupedal robot with variable dynamic locomotion and perception-free terrain adaption. A [15] morphologically adaptable quadruped robot for unstructured situations DyRET which is a dynamic robot for embodied testing, offers a strong proof of concept that uses a changing morphology to respond to realistic, outside situations. The research [16] efforts toward robot autonomy have culminated and offered a solution for the robot to detect impassable impediments in its route since the work was done in controlled conditions with user-guided velocity instructions and straightforward stiff paths that lacked cognitive planning.

Quadrupedal walking and running sequence optimization for refining the motions exerted is attempted on a 28kg weighing motor powered cable driven StarlETH [17] robot. Anymal [18] a quadruped robot weighing about 30kg built especially for travelling through rugged and uneven terrain was purpose built for industrial environment. The model is equipped with series elastic actuator and owes a cluster of sensors for surveillance activities and is fully autonomous, water and dust proof. ALPHRED [19] is a quadruped delivery robot with high power mechanoreceptors actuators. It is capable of dynamic trotting, continuous walking, sprinting, and manoeuvring, and while picking up a package, it may even be able to walk like a biped. A full gait planning system [20] integrating inverse kinematics is developed utilising a classical compound pendulum equation and an omnidirectional bionic construction. Kinematics and dynamics were investigated using MATLAB, simulations were run using Adams software, and real-time testing was completed.

The diverse information gathered from the literature review was helpful in designing this project in a variety of ways. Transmission of power to the leg was achieved through diverse mechanisms like mechanical link, cam operated, Bowden cable, dc motor powered, hydraulic, stepper and servo powered Every piece of literature has pros and weaknesses that were carefully considered in order to create a solid model. The various gait patterns for crawl, walk and trot with various speeds were elaborately studied. Robustness was one vital parameter to be considered in building the model for offering adaptive reflexes with reptile-like locomotion. Many defence research agencies have entered into the field for enhancing and optimizing the quadruped design for developing advanced autonomous and flexible robots for surveillance and defence applications. A detailed evaluation and comparison between the quadruped design and wheeled robot is as elucidated in the Figure 1. The goal of this project was to create a robot that could traverse terrain that is impassable to most other road vehicles.

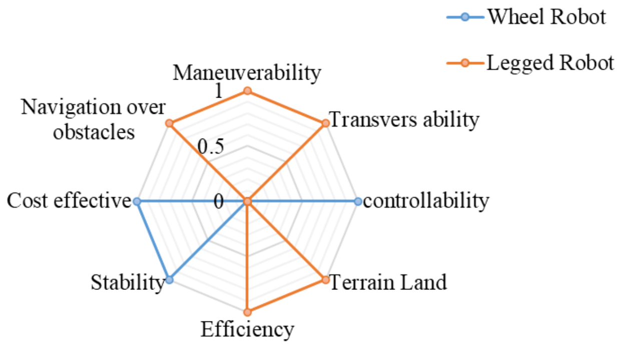

Fig.1 Technical comparison of quadruped and wheeled robot

The focus of this research is to create a legged robot that is scalable through IOT principles, versatile, quick, accurate, affordable, and based on logic. For the study of risky zones or zones that cannot be reached by people or conventional vehicles, a dynamic system that can track terrains and respond both manually and autonomously is needed. A system that gathers data, stores it in the cloud, and processes it to get further understanding of the issue.

2. Design Analysis

Animal motor behaviours exhibit a variety of characteristics. Consciousness, vestibular reflexes, and regulatory requirements are a few of these essential traits that are paramount to achieving adaptable and flexible locomotor behaviours. The ability to generate spontaneous, self-organized locomotion is represented by manoeuvring self-organization. In reaction to unforeseen events like gradients in the ground plane and external disruption, vestibular reflexes and compliance can increase the functioning of self-organized mobility. Therefore, comprehending the biological underpinnings of these characteristics aids in illuminating the fundamental mechanisms underlying the genesis of adaptive locomotion and the ensuing creation of sophisticated artificial robot manipulators.

The most common configuration for robots with four legs is two rows of two legs (2+2) or at a 120-degree angle, evenly spaced from the centre. A walking robot needs to be dynamically stable and moving in order to stay upright. The robot might fall over if it stopped walking because of its centre of mass. A robot that is statically stable won't topple over if its gait is interrupted at any time. A quadruped will be statically stable as long as all three of its legs are always in touch with the ground and as long as its centre of mass is contained within the triangle formed by its three feet.

Additively manufactured model using Fusion Deposition Modelling (FDM) 3D printing technology is made use of in this methodology for modelling the individual components like tibia, femur and coxa of the quadruped robot. Figure 2 depicts the overall 3D-designed model of the intended spider robot. The functional block diagram of the proposed system is as elucidated in the Figure 3.

The weight bearing structure tibia bone found medial to fibula is fabricated and coupled with the femur bone which is the strongest and longest bone of the spider limb connected with coxa which are modelled with Fusion 360 software as individual parts, analysed and 3D printed and ensured for structural rigidity. Figure 4 shows a constructed and entirely functional spider bot. Figure 5 depicts the control and drive system's electrical schematic.

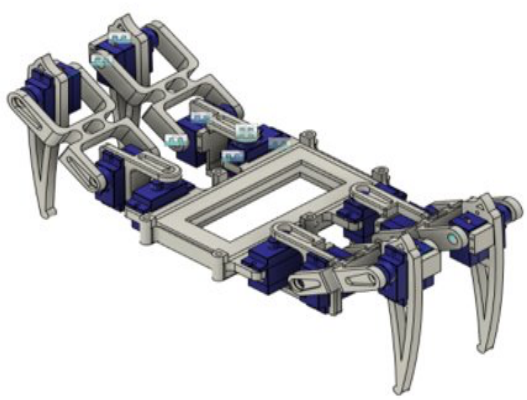

Fig. 2. 3D model of the spider bot in Isometric view

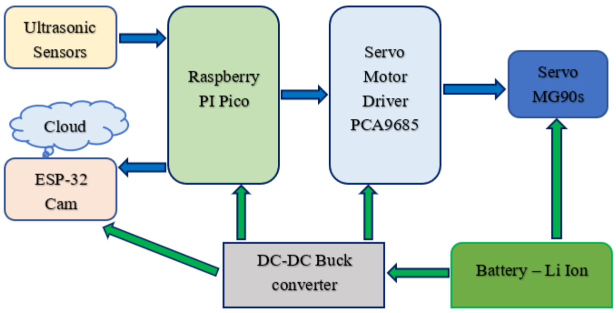

Fig. 3. Overall functional block diagram

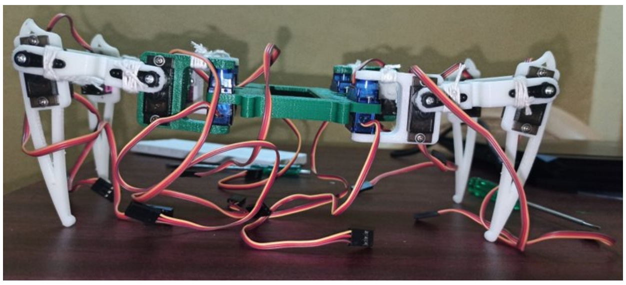

Fig. 4. Fabricated model of spider bot

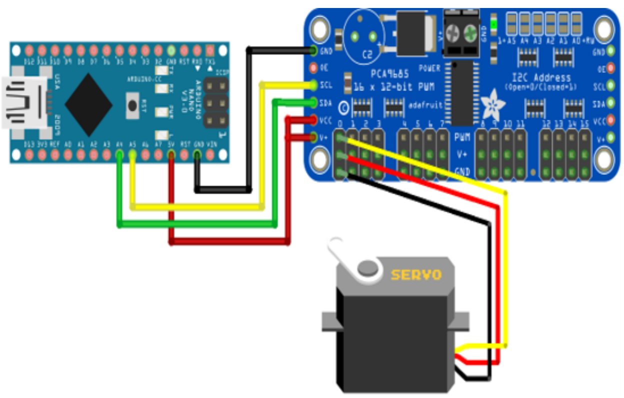

Fig. 5. Control schematic of spider bot

Equipping Raspberry PI Pico as its main microcontroller and using a servo controller shield to control the individual joints of leg joints of the quadruped robot. The apparatus has an ESP-32 cam module which is used to obtain vision data from the environment and provide feed of the environment in which the bot is traversing to the hub for enabling surveillance. Since the ESP-32 Cam hardware has a little amount of memory and the microSD card will only be used to store the dataset and runtime buffer data, the code has to be streamlined sufficiently to allow the controller to process the vision without a delay in transmission for enabling real-time transfer. Raspberry PI Pico is so chosen since it has the highest memory in its comparison without compromising in the cost perspective as well it offers a wide support for integration with ESP devices via micro python. The mathematical modelling for joint torque analysis is elaborated in the equations below. Let N be the normal reaction forces, L be the link length, W be the weight on each joint, T be the torque on each joint. Let the torque equation of the foot be written as shown in the Equation (1),

$$\sum T_{foot} = (-W_1 * (L_1 * \cos\theta_1)) - (W_2 * (L_1 * \cos\theta_1 + L_2 * \cos\theta_2)) - (W_3 * ((L_1 * \cos\theta_1 + L_2 * \cos\theta_2)) - (W_4 * ((L_1 * \cos\theta_1 + L_2 * \cos\theta_2 + L_3)) - (2W_3 * ((2L_3 + L_1 * \cos\theta_1 + L_2 * \cos\theta_2)) - (2W_2 * ((L_1 * \cos\theta_1 + 2L_2 * \cos\theta_2 + L_3)) + (2N_2 * ((2L_1 * \cos\theta_1 + 2L_2 * \cos\theta_2 + 2L_3)) \quad (1)$$

The torque equation of the knee joint may be illustrated as follows in the Equation (2) as follows,

$$\sum T_{knee} = T_1 - (N_1 * (L_1 * \cos\theta_1)) - (W_2 * (L_2 * \cos\theta_2) - (W_3 * (L_2 * \mathrm{Cos}\,\theta_2)) - (W_4 * ((L_2 * \cos\theta_2 + L_3)) - (2W_3 * ((L_2 * \cos\theta_2 + 2L_3)) - (2W_2 * ((L_2 * \cos\theta_2 + 2L_3)) - (2W_1 * ((2L_2 * \cos\theta_2 + 2L_3)) + (2N_2 * (2L_2 * \cos\theta_2 + 2L_3 + L_1 * \cos\theta_1)) \quad (2)$$

The torque equation of the hip joint is as elaborated in the Equation (3) as follows,

$$\sum T_{hip} = T_2 - \left(N_1 * (L_1 * \cos\theta_1 + L_2 * \cos\theta_2)\right) + \left(W_1 * (L_2 * \cos\theta_2)\right) - (W_4 * L_3 - 2W_2 * L_3 - 2W_3 * L_3) - \left(2W_1 * (2W_3 + L_2 * \cos\theta_2)\right) + (2N_2 * (2L_3 + L_2 * \cos\theta_2 + L_1 * \cos\theta_1)) \quad (3)$$

Torque equation at shoulder joint is as shown in the Equation (4) below,

$$\sum T_5 = T_1 - (F_1 * (L_1 * \cos\theta_1 + L_2 * \cos\theta_2) - (L_3 * W_x) + (2F_2 * (2L_3 + L_1 * \cos\theta_1 + L_2 * \cos\theta_2)) \quad (4)$$

3. Results and Discussion

A statically stable robot won't fall over if its gait is ever halted. A hexapod's center of mass is located within the triangle formed by these feet, as illustrated in Figure 6, and it will be statically stable as long as three of its legs are continually in touch with the ground. From the free body diagram angle calculations were arrived which is as depicted in the Figure 7.

A quadruped will be statically stable as long as three of its legs are consistently in touch with the ground. For the purpose of choosing the motor torque, the maximum torque needed at a certain joint (when one of the robot's legs shifts up while the other three support the robot) is all that is necessary. Given that, with one leg up, the torques T1 and T2 are bigger than T3 and T4, respectively. Therefore, as T1 and T2 represent the maximum actuator torque selection range, their calculation is sufficient. Calculation results show that T1=2 kgf-cm is the maximum torque needed for the constructed model.

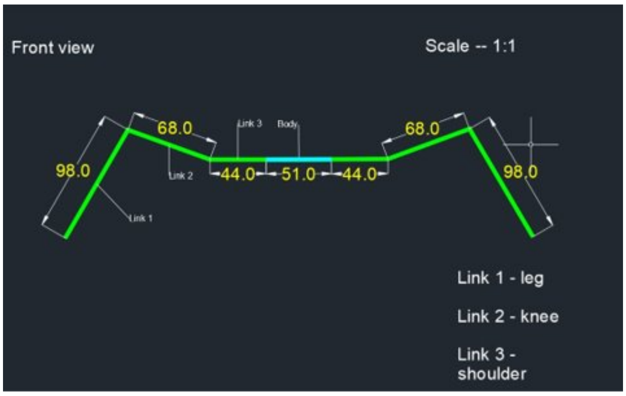

Fig. 6. Free body diagram in front view of spider bot

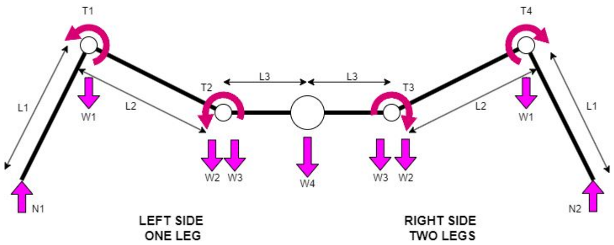

Fig. 7. Angle calculation from free body diagram of spider bot

The walking pattern for the quadruped robot for maintaining the dynamic stability during manoeuvring with starting position being two legs extended out on a side whilst the other two legs being pulled inward and the sequence will continue as elaborated in the Figure 8. The waking pattern by picturising a movement diagram using the joint coordinates along the X and Y axes over the top view of the model with is shown in Figure 9. The bot manoeuvres around the coordinates by using vision guides and with the aid of a pair of cost-effective ultrasonic sensors for obstacle detection and path planning which is done also involving the vision system by which the ESP-32 Cam sends the run-time data to the Raspberry PI Pico through micro python interface and decision is taken accordingly combining the sensor and vision data. A memory card is attached to the ESP32 CAM module has a built-in micro-SD card slot by which the environment in which the bot manoeuvre is recorded and is pushed to the cloud with the help of WiFi which is the current limitation of the developed model and that can be overcome by equipping with a GSM module through which the video could be sent to the cloud independently without relying on public network.

In this light weight [3] quadruped robot, the foot-end trajectory and inverse kinematic solutions are coupled to complete the gait planning. This quadruped robot is equipped with a classical compound pendulum equation. The quadruped robot has the ability to manage the roll and pitch angles of its torso during the diagonal trot gait trial and self-balancing test. Whereas the prototype aims to develop a scalable, versatile, rapid, accurate, reasonably priced, and logic-based legged robot. The prototype is statically stable, meaning it won't fall over if its gait is ever halted. on the other hand, the prototype is easier to use and troubleshoot than the HyQ2Max [4], which is more complicated and requires a specialist to run. Furthermore, HyQ2Max is heavier than the prototype, making it less adaptable to specific surfaces due to the weight of the hydraulic control system.

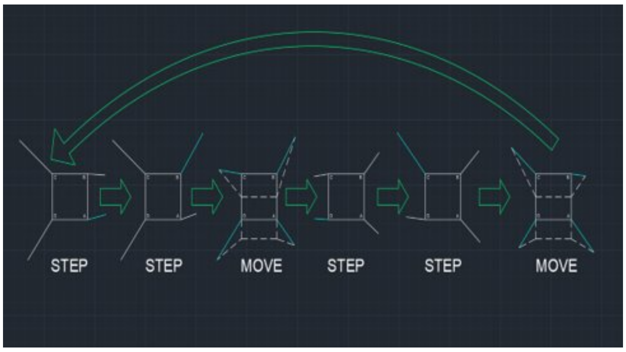

Fig. 8. Walking pattern for the spider bot

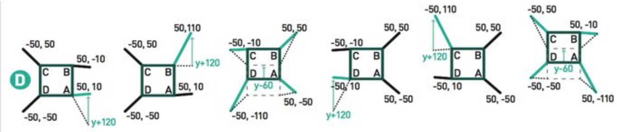

Fig. 9. Movement diagram with Joint coordinates for the spider bot

4. Conclusion

The best alternative to the current robot or human intervention system for data collection from locations where people and conventional automobiles cannot go is a quadruped robot. This technology would revolutionize the way people search for their loved ones after a natural disaster like an earthquake, volcanic eruption, snowstorm, etc. with complex geography and a chilly environment. Quadruped systems can be deployed in conflict areas and used to carry out demanding 12 DOF tasks in an energy-efficient manner. The body is abrasion resistant, so we must deploy it and ensure that it is statically stable. Robust built and dynamic stability for enabling the fast manoeuvre in rough and rugged terrains. The proposed arrangement could be improved by including a wireless controller and a group of sensors with cameras to gather data in a variety of locations where humans seem to be unable to. The developed model is fast, reliable, cost effective and rugged enough to run in real-time test environments.

We have used an ESP-32 Cam hardware for the objective of achieving applications like rescue mission and navigation. But if the prototype needs to be used for defense and security related applications, it is ideal to use nitrogen-filled camera with IR-cut sensor as they function by blocking undesired IR light to keep it from altering the colors of daytime images, making them appear much more realistic. The IR-cut filter turns off while the camera is in night mode, allowing the camera's light sensitivity to drop to extremely low lux levels. It is also advisable to include a short band wave to transfer encrypted data to the secure network.

References

1. W.K.Huang, J.Xiao, F.Zeng, P.Lu, G.Lin, W.Hu, X.Lin, and Y.Wu, “A quadruped robot with three-dimensional flexible legs,” *Sensors*, 21(14), 2021, pp 1-18/

2. C.Sun, M.Yuan, F.Li, Z.Yang, and X. Ding, “Design and Simulation Analysis of Hexapod Bionic Spider Robot”. In *Journal of Physics*: Conference Series, 1168 (2), 2019, pp. 1-6.

3. Y.Shi, S.Li, M.Guo, Y.Yang, D.Xia, and X.Luo, "Structural design, simulation and experiment of quadruped robot," *Applied Sciences*, 11(22), 2021, pp. 1-19.
4. C.Semini, V.Barasuol, J.Goldsmith, M.Frigerio, M.Focchi, Y.Gao, and D.G.Caldwell, "Design of the Hydraulically Actuated, Torque-Controlled Quadruped Robot HyQ2Max," IEEE/ASME *Transactions on Mechatronics*, 22(2), 2017, pp. 635–646.
5. D.Ayakl Robotlar İçin Hidrolik Tahrikli Bir, M.Kalyoncu, M.Arif Sen, and V.Bakircioglu, "Bacak Geliştirilmesi-Development of a Hydraulically Actuated Leg for Quadruped Robots View project Inverse Kinematic Analysis Of A Quadruped Robot," *International Journal of Scientific & Technology Research*, 6(9), 2017, pp. 285-189.
6. K.Hamza, K.Satoshi, F.Marco, C.Marco, B.Victor, F.Roy, C.G.Darwin, and S.Claudio, "Development of the Lightweight Hydraulic Quadruped Robot – MiniHyQ," In: *2015 IEEE International Conference on Technologies for Practical Robot Applications (TePRA),* 2015, pp.1-6.
7. B.Sandeep, and P.Tamil Selvan, "Design and Development of an Autonomous Quadruped Robot," *IOP Conference Series: Materials Science and Engineering*, 1012(1), 2021, pp. 1-20.
8. S.Rajesh Babu, K.Senthil Kumar, G.Sabari Narayanan, R.Raja, K.Anbazhagan, and H.Yasar Sathab, "Design and conception of Arduino based quadruped robot," In: *Materials Today: Proceedings*, 2021, pp. 1-6.
9. R.Jain, "Spider Robot - An Eight Leg Waking Robot," *International Journal for Research in Applied Science and Engineering Technology*, 7(4), 2019, pp.1586–1589.
10. J.Kim, T.Kang, D.Song, and S.J.Yi, "Design and control of a open-source, low cost, 3d printed dynamic quadruped robot," *Applied Sciences*, 11(9), 2021, pp. 1-18.
11. C.Yan, K.Shi, H.Zhang, and Y.Yao, "Simulation and analysis of a single actuated quadruped robot," *Mechanical Sciences*,13(1), 2022, pp.137–146.
12. P.Biswal, and P.K.Mohanty, "Development of quadruped walking robots: A review," *Ain Shams Engineering Journal*, 12(2), 2021, pp.2017–2031.
13. D.Kim, D.Carballo, J.D.Carlo, B.Katz, G.Bledt, B.Lim, and S.Lim, "Vision Aided Dynamic Exploration of Unstructured Terrain with a Small-Scale Quadruped Robot," In: *2020 IEEE International Conference on Robotics and Automation (ICRA*)*,* 2020, pp.2464-2470.
14. L.Wang, L.Meng, R.Kang, B.Liu, S.Gu, Z.Zhang, F.Meng, and A.Ming, "Design and Dynamic Locomotion Control of Quadruped Robot with Perception-Less Terrain Adaptation," *Cyborg and Bionic Systems,* 2022, pp.1–10.
15. T.F.Nygaard, C.P.Martin, J.Torresen, K.Glette, and D.Howard, "Real-world embodied AI through a morphologically adaptive quadruped robot," *Nature Machine Intelligence*, 3(5), 2021, pp.410–419.
16. T.Dudzik, M.Chignoli, B.Bledt, B.Lim, A. Miller, D.Kim, and S.Kim, "Robust autonomous navigation of a small-scale quadruped robot in real-world environments," In: *IEEE International Conference on Intelligent Robots and Systems*, 2020, pp.3664–3671.
17. C.Gehring, S.Coros, M.Hutter, C.D.Bellicoso, H.Heijnen, R.Diethelm, M.Bloesch, P.Fankhauser, J.Hwangbo, M.Hoepflinger, and R.Siegwart, "Practice Makes Perfect: An Optimization-Based Approach to Controlling Agile Motions for a Quadruped Robot," *IEEE Robotics and Automation Magazine*, 23(1), 2016, pp.34–43.
18. P.Fankhauser, and M.Hutter, "ANYmal: A Unique Quadruped Robot Conquering Harsh Environments," *Engineering and Tech Library*, 2018, pp.54–57.
19. J.Hooks, M.S.Ahn, J.Yu, X.Zhang, T.Zhu, H.Chae, and D.Hong, "ALPHRED: A Multi-Modal Operations Quadruped Robot for Package Delivery Applications," *IEEE Robotics and Automation Letters,* 5(4), 2020, pp. 5409–5416.
20. Y.Shi, S.Li, M.Guo, Y.Yang, D.Xia, and X.Luo, "Structural design, simulation and experiment of quadruped robot," *Applied Sciences*, 11(22), 2021, pp. 1-18.