DOI: https://doi.org/10.33103/uot.ijccce.24.3.1

Advancements in Legged Walking Robots: Review

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***Abstract*—*The purpose of this review paper is to contribute to the body of knowledge surrounding legged walking robots, specifically those utilizing four legs. It aims to inform researchers, engineers, and enthusiasts about the advancements, potential applications, and future prospects of these robots, ultimately driving further research and development in this exciting field. The review covered the most recent research articles in the field of designing and manufacturing robots, as well as how to choose the mechanism of actuator between hydraulic or electric systems and their impact on the weight increase and energy consumption, or potential noise generation during the operation like Bigdog robot. The payload was also assessed, with a comparison of the speed chart for each quadruped robot. It has been found that several critical technologies driving quadruped robots' advancement include new biomimetic structures, high power density actuators, techniques for controlling in real time and integrated environmental perception, depending on the application fields, such as industrial automation, healthcare, and exploration. Each of these elements is essential for achieving high-performance quadruped robots. Notably, the paper also delves understanding the fundamental methods used by mobile robots to perceive their surroundings, pay load (N), normalized speed (m/s), and engine mechanism. This work is valuable for all researchers in the field of a five-bar mechanism legged robot to keep up with the most recent advancements in this field. Furthermore, this review paper can be considered as a guideline for researchers who are intended to perform further research on mobile robot.*

Index Terms: *Quadruped mobile robot, Payload, Mechanism, DOF, robotic leg.*

I. INTRODUCTION

The available recent review articles related to the area of four-legged robot focused on the various design and development approaches for the quadrupedal robot, and the environment perception techniques are discussed [1], [2], [3]. Some made a review on a comparative study of robotic manufacturing cost between its proposed robot and previously established robots to keep the price low and its upkeep simple [4]. Other introduced a review on mechanism, sensing, and performance evaluation stair-climbing robots [5], or some summarized a review about swimming central pattern generators [6]. The purpose of this review paper is to provide an in-depth analysis and comprehensive overview of legged robots, with a specific focus on those utilizing 4 legged systems. This paper aims to explore the advancements, characteristics, applications, challenges, and the impact they are making across different domains by focusing on pay load (N), normalized

Received 13/December/2023; Accepted 15/May/2024

Iraqi Journal of Computers, Communications, Control & Systems Engineering (IJCCCE), Vol. 24, No. 3, September 2024

DOI: https://doi.org/10.33103/uot.ijccce.24.3.1

speed (m/s), and mechanism of actuator of all robots in previous research, because of their ability to adapt to the terrain and explore how these robots can augment the human capabilities, improve the efficiency, and access the areas that are otherwise difficult, or the walking robots are better suited to such conditions and the future prospects of these robots. In recent years, the field of robotics has witnessed remarkable advancements, particularly in the development of legged robots [4], [7], [7]. Where; since ancient times, humans have been intrigued by the idea of creating machines that bear a resemblance to living organisms, and in some cases, even to humans themselves. The origins of robots can be traced back to the Greek engineer Ctesibius, who lived around 270 B.C. Ctesibius, drawing upon his expertise in pneumatics and hydraulics, applied his knowledge to create innovative inventions, such as the first organ and water clocks featuring moving figures. These early Greek entertainment robots were primarily designed for specific, repetitive tasks and did not need to perform more complex or demanding functions [8]. These cutting-edge machines, inspired by the natural movement of animals, are paving the way for unprecedented opportunities in various industries. From the exploration and disaster response to manufacturing and entertainment, the legged robots are proving to be versatile and adaptable, revolutionizing the way it perceives and utilizes robotics [9]. Therefore, a research on walking robots has become a hotspot in the field of robotics as in [10], coinciding with the advent of legged bionic robots as mentioned in [11], [12], [13]. In the realm of contemporary robotics, systems can be broadly categorized into two main areas: Manipulation robotics and mobile robotics [14], [15], [16]. When focusing on mobile robotics and the choice of locomotion strategy [17], several key aspects of the problem need to be taken into account:

- The specific requirements of the task that the robot is intended to perform [19].
- The constraints imposed by the terrains in which the robot will operate.
- The limitations inherent to the chosen actuators for locomotion [18], [19].
- The availability of a suitable power source to provide energy to the robot and achieve the desired level of autonomy [20].

Considering these concepts, there are three primary configurations available for the locomotion of mobile robots on the ground:

- Rotational devices, including wheels and tracks [21].
- Legged structures, resembling those found in animals.
- Articulated structures akin to the body of a snake.
- Each of these locomotion configurations possesses distinct characteristics that render them suitable for specific classes of applications.

II. MOBILE ROBOTICS

A. Wheeled and Tracked Vehicles

Wheeled vehicles were and still being the predominant means of locomotion. Their utilization for various tasks has become so widespread [22], [23], [24], [25], . However, it is important to acknowledge that the wheeled vehicles are best suited for paved or regularly maintained surfaces. The wheeled mechanisms can be relatively simple and lightweight [26], [29], [27].

Nevertheless, it is crucial to recognize that more than 50% of the Earth's surface is inaccessible to traditional wheeled or tracked vehicles [28]. These vehicles encounter significant difficulties, or even impossibility, when confronted with large obstacles and

Received 13/December/2023; Accepted 15/May/2024

ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

DOI: https://doi.org/10.33103/uot.ijccce.24.3.1

uneven terrain. Even so-called all-terrain vehicles can only navigate small obstacles and uneven surfaces, often at the cost of high energy consumption [29].

B . Legged Robot:

A substantial part of the Earth is inaccessible to any sort of wheeled mechanism. In fact, natural obstacles, like large rocks, loose soil, deep ravines, and steep slopes conspire to render rolling locomotion ineffective. The moon and other planets present similar terrain challenges. In many of these natural terrains, legs are well-suited for implementing the locomotion. Legged robots have been constructed utilizing various leg configurations, including those with one, two, three, four, and potentially more legs. The prevalent trend is to employ an even number of legs, as it facilitates efficient gaits and enhances stability performance, a principle widely acknowledged [30], [31].

So, firstly, legged robots exhibit a higher degree of adaptability when traversing rough terrains [32], [33]. Unlike wheeled or tracked robots that leave long continuous tracks, the movement of a legged robot is characterized by a sequence of distinct footprints. In reality, challenging terrains often consist of a variety of obstacles, such as rocks, soil, sand, inclines, and cliffs. Consequently, the viable paths that can safely support a vehicle are limited. This renders wheeled and tracked robots ill-suited for such terrains. In contrast, legged robots require only the discrete points of contact with the terrain, allowing them to navigate unimproved landscapes with greater ease. Moreover, their interaction with the environment causes a minimal damage, making them environmentally friendly.

Secondly, a legged robot offers an enhanced mobility and flexibility due to the multiple degrees of freedom in each of its legs [34], [35]. Furthermore, during the locomotion, a legged robot can adjust the length of its legs to maintain its body level and modify the extension of its legs to position its center of gravity. As a result, legged robots are less susceptible to tipping over and demonstrate higher reliability.

Thirdly, a legged robot effectively isolates its body from the underlying [36], allowing independent movement of its body while maintaining fixed foot positions. This enables legged robots to precisely maneuver their bodies in three dimensions, facilitating the measurements of terrain surfaces using scientific instruments and tools [37].

Utilizing discrete footholds in the ground can also lead to the improved energy efficiency. When navigating uneven terrain, the energy required to traverse depressions is reduced compared to continuous contact (Bekker, 1960).

In general, the exploration of legged robots was commenced in the 1960s. However, it was not until the 1980s that research on the dynamically stable legged robots gained a significant attention, largely attributed to Raibert's groundbreaking work on running robots. Raibert successfully developed running robots with one, two, and four legs, which set the standard for evaluating the robot performance that still persists today [38].

Since then, researchers worldwide have dedicated substantial efforts to the developing and refining the legged robots as platforms for design and control studies, yielding promising results. The majority of investigations have focused on two-legged, four-legged, and six-legged robots, while research on one-legged and eight-legged robots has been comparatively limited.

i. One legged robot:

The Monopod is a unique planar robot that features a single leg, [39], [40], [41]. What sets the Monopod apart from previous robots is its utilization of an articulated leg instead of a telescoping one. Moreover, unlike the air springs used in other running robots, the Monopod's leg as shown in *Fig. 1* is equipped with a leaf spring. The primary focus of the

Received 13/December/2023; Accepted 15/May/2024

ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

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Monopod was to explore the capabilities and advantages of articulated legs incorporating rotary joints. These legs offer several mechanical benefits, including a lower moment of inertia, reduced unsprung mass, a wider range of motion, greater compactness, improved ruggedness, and simplified construction. During testing, the Monopod achieved an impressive maximum running speed of 2.3 m/s (5.1 mph) over an average distance of 16 m. This demonstrated the feasibility and potential of using articulated legs for efficient and dynamic locomotion.

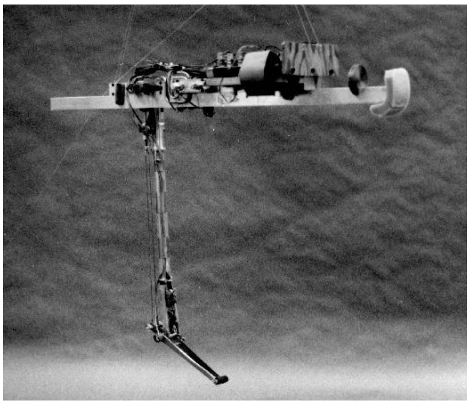

FIG. 1. A SINGLE ROBOT LEG MONOPOD [39].

ii. Two legged robot:

Honda Motors in Japan has showcased a series of bipedal walking robots, namely P1, P2, P3, and ASIMO, as depicted at *Fig. 2* [40], [42], [41]. Each of the subsequent iteration of these robots represents the advancements in robotic technology. Robot P1 had the capability to independently accomplish specific tasks in familiar environments and could handle some unknown tasks in uncertain environments with operator assistance. Notably, P1 did not carry the necessary computers, power systems, image processing, and motion planning components on the robot itself. The focus was on achieving the coordinated motion of the legs and arms, while the computational aspects were supported externally.

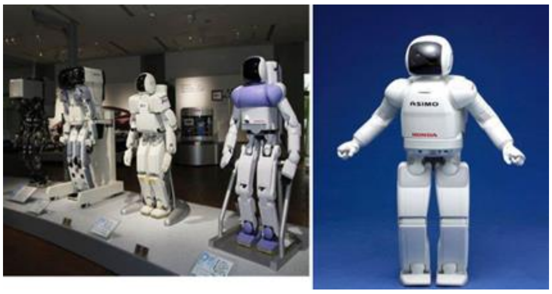

FIG. 2. P2, P3 AND ASIMO HUMANOID ROBOTS OF HONDA, RESPECTIVELY. [43].

Bipedal robots face two primary challenges: Stability control and motion control. Stability control is a critical aspect for bipedal systems as they need to maintain balance [44], [45], even when at rest. Achieving stability in the forward-backward direction is particularly challenging. Some robots, especially toys, address this issue by incorporating large feet, which enhance the stability but limit the mobility. More advanced systems utilize sensors, like accelerometers or gyroscopes to provide real-time feedback, mimicking the balance of a human. These sensors are also employed for motion control and walking. The complexity of these tasks often necessitates the use of machine learning techniques. The notable examples of two-legged robots include Boston Dynamics' Atlas, toy robots, like

Received 13/December/2023; Accepted 15/May/2024
 ISSN (Print) 1811-9212 *ISSN (Online) 2617-3352*

DOI: https://doi.org/10.33103/uot.ijccce.24.3.1

QRIO and ASIMO, NASA's Valkyrie robot designed for human assistance on Mars. These robots showcase the advancements in bipedal robot technology and their diverse applications.

The concepts of bipedal robots, built to mimic human walking, involve advanced technologies to simulate natural walking motion. These robots are considered a significant engineering challenge due to the complexity of walking and maintaining balance. the concepts of bipedal robots include:

Structure Design: Designing the robot's structure requires the ability to withstand weight and maintain balance during movement. Advanced materials such as aluminum or carbon are often used to provide necessary strength and rigidity.

Motors and Joints: Bipedal robots feature multiple motors and joints that simulate the movement of human legs and feet. These motors are programmed to achieve natural walking motion, including steps, bends, and balance.

Sensors: Robots are equipped with various sensors such as infrared, X-ray imaging, ultrasound imaging, and others to enhance environment recognition and obstacle avoidance during walking.

Control and Programming: Robots are programmed with advanced control systems to execute the required movements for proper and stable walking.

Modification Techniques: Concepts of bipedal robots are continually being developed and improved, including advancements in control techniques and better interaction with the environment. By utilizing these concepts, bipedal robots can achieve movement similar to human walking, allowing them to effectively interact with the environment and perform various tasks efficiently.

The drive and control systems of biped walking robots are essential for enabling them to achieve human-like walking motion with stability and efficiency. These systems combine mechanical design, sensor feedback, and advanced control algorithms to generate dynamic and responsive walking behavior. Additionally, adaptive control, where Some advanced biped walking robots incorporate adaptive control techniques to adjust their behavior in response to terrain changes, payload variations, or other environmental factors. These adaptive control strategies may include learning algorithms or neural networks that improve the robot's walking performance over time.

iii. The quadruped robot:

The most optimal selection for legged robots in terms of mobility and stability during locomotion is the quadruped robot. Quadrupeds are unique among all legged robots because it is easier to manage, create, and maintain a robot with four legs than it is to maintain a robot with two or six legs. Researchers have long been inspired by the biological locomotion of running gaits in quadrupeds, which allows them to carry significant payloads and maintain balance. Early on, researchers began working on achieving real-time speed and natural movements akin to animals, like cows, dogs, and cheetahs by developing control systems and dynamic gait generation for quadruped robots [46], [47], [48].

Over the years, extensive research has been conducted on the walking patterns and energy consumption of animals, and a similar line of study has been pursued in the development of quadruped robots [49], [50],[51]. In 1980s, the first comprehensive investigation into the kinematics of quadruped robots for mammals was started by Marc Raibert of MIT and Shimoyama of Tokyo University [52]. The Hirose Fukushima Robotics Lab has spent about since 1976 40 years to the study of legged robots, with a particular

Received 13/December/2023; Accepted 15/May/2024
 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

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focus on quadruped robots. The renowned TITAN series, mostly electrically actuated, with TITAN VIII being particularly popular and widely used in Japanese universities and research institutes [55]. The latest addition to the TITAN series is TITAN XII, boasting the ability to surmount significant obstacles and reach a maximum speed of 1.5 m/s, controlled by an external PC and an internal microcontroller [56].

Additionally, a number of TITAN robots, including TITAN VII and TITAN XI, as revealed at *Fig. 3*, have exhibited their ability to operate effectively on steep inclines. Meanwhile, TITAN IX is specifically designed for humanitarian mine detection and removal [57], [53], [54]. Starting from the late 1980s, the research in quadruped robots has diversified, leading to the development of various models like, The first comprehensive investigation into the kinematics of quadruped robots for mammals was started by Marc Raibert of MIT and Shimoyama of Tokyo University [52]. The Hirose Fukushima Robotics Lab has spent about since 1976, as illustrated in *Fig. 3*. [55], [56], [57], [58].

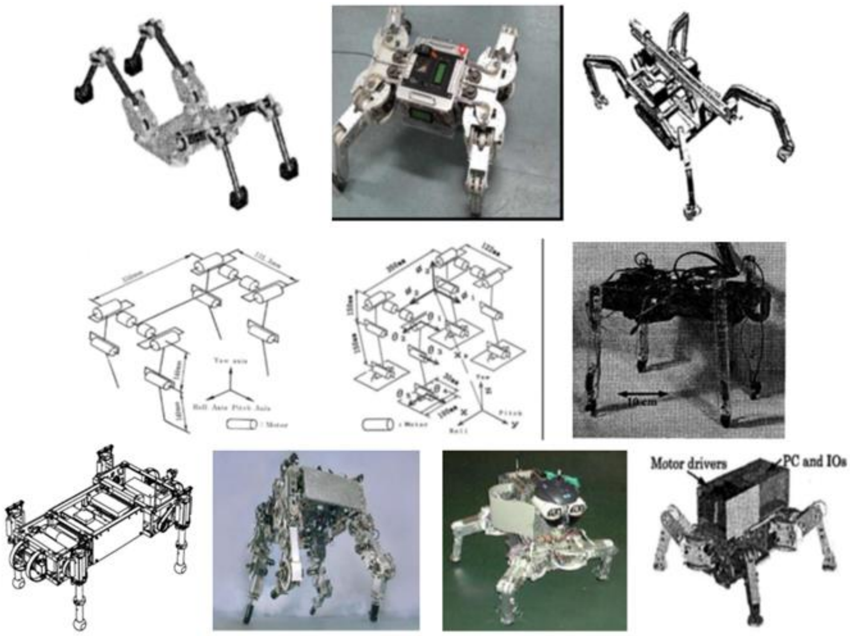

FIG. 3. (A) TITAN VIII; (B) TITAN IX; (C) TITAN XI; (D) COLLIE-I; (E) COLLIE-II; (F) SCOUT-I; (G) SCOUT-II; (H) WRAP1; (I) JROB-1; AND (J) JROB-2, RESPECTIVELY.

Notably, after 2000, quadruped robot performance improved dramatically. For example, Kimura et al.'s Tekken IV used Central Pattern Generator (CPG) to control leg motion and perform various gaits. The Spanish Council for Scientific Research created SILO4 in 2003, served as a platform for fundamental research and practical applications of quadruped robots, being electrically actuated and capable of navigating simple terrains outdoors. The collaboration between Ohio State University and Stanford University led to the creation of OSU-Stanford Quadruped (OSQ), capable of reaching a top speed of around 4.15 m/s for a single leg. But then, in 2007, the OSQ was developed, resulting in KOLT, which focused primarily on the limbs moving in a gallop motion [59], [60], [61], [62].

MRWALLSPECT III was developed and specifically engineered to ascend inclines with concave corners while preventing tumbling and leg slipping. Subsequently, AiDIN I was created in 2007 and AiDIN III in 2013, both quadruped robots with varying capabilities, including a trot gait that enables AiDIN III to climb a slope of 20° and carry a maximum load of 3 kg [63], [64]. The qRT-1, presented at the 35th Chinese Control

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ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

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Conference in 2016, is a mobile machine that has two wheels and two legs. On even ground, it can trot as fast as 1.3 m/s, and on rough ground, 0.7 m/s. It also has the ability to carry a burden exceeding 40 kg and can climb and descend a 20° inclination. A different innovation was made for study on energy minimization: the quadruped walking robot P2 [65]. A quadruped robot named "Kotetsu" was proposed by the Paulo Kyoto Institute of Technology [66], [67]. It can dynamically walk in the low- to medium-speed range and achieve rhythmic motion in each leg depending on loading and unloading information. The VU quadruped, a pneumatically operated quadruped robot that can carry a burden of 9.1 kg, or 130% of its weight, was explained by Vanderbilt University [68]. It has a 9.1-kilogram payload capacity, or 130% of its total weight. The external hydraulic actuated quadruped robot MBBOT [69] was built by Harbin Institute of Technology. It has force sensors and an Inertial Measurement Unit (IMU) and can run 0.83 m/s on a treadmill. "Baby Elephant" is the name of the quadruple robot that Shanghai Jiao Tong University created in 2013. [70], capable of reaching a maximum speed of 1.8 km/h and carrying a maximum load of 100 kg on different types of terrains. In 2013, A bionic quadruped robot was created by Beijing Institute of Technologies. [71]. The National University of Defense Technology conducted experiments involving time marking, squatting, walking, and trotting with their quadruped robot. To achieve a maximum trotting speed of 3 km/h, an operation space model and a position/force control technique were proposed to enhance the robot's adaptability to different environments [72]. In 2010, the Shandong University Robotics Center introduced Scalf-1 [73], a quadruped robot measuring approximately 1100×490×1000 mm and weighing 123 kg. Scalf-1 demonstrated impressive capabilities, being able to climb slopes with angles over 10° and traverse obstacles up to 150 mm high. During testing, the robot achieved a top speed of 5 km/h while trotting and crawling. The research group further assessed its performance in challenging terrains, navigating slopes, withstanding lateral impacts, and carrying heavy burdens. Subsequently, in 2012, they made enhancements to Scalf-2 [74], improving its hydraulic power system and biomimetic structure. Scalf-2 was equipped with a servo controller boasting 12 channels, an IMU, and force sensors. In 2014, the China North Vehicle Research Institute revealed their quadruped robot during the China International Emergency Rescue Expo [75]. This robot weighed 130 kg and revealed impressive capabilities, capable of carrying a burden of 50 kg while walking on various terrains and achieving a maximum speed of 6 km/h. The robot HyQ [76], [77], shown in *Fig. 4* (a), is a creation of Claudio Semini and his team. It has twelve torque-controlled joints that are driven by electric and hydraulic actuators. This platform is specifically made to study both the navigation of difficult terrains [79], [80], as well as extremely dynamic actions like hopping, jumping, and running [78]. The robot was further improved in 2015 to create HyQ2Max and HyQ2Centaur [81], focusing on robustness, self-righting capability, and manipulation studies. The robot was equipped with on-board sensors for location, force, and pressure. The Massachusetts Institute of Technology (MIT) created a highly effective four-legged robot called MIT Cheetah in 2013 [82]. Many researchers applied a set of four guidelines for design to minimize the energy loss during the locomotion. The robot consumes approximately 973 W of power, similar to that of running animals [83]. In 2015, MIT developed MIT Cheetah-2, incorporating a novel algorithm that enables untethered running at speeds ranging from 0 to 4.5 m/s in a stable manner, as portrayed in *Fig. 4* (b) [84]. Operating at a speed of 2.5 m/s, the robot is capable of jumping over obstacles that are 400 mm high.

Received 13/December/2023; Accepted 15/May/2024
 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

DOI: https://doi.org/10.33103/uot.ijccce.24.3.1

FIG. 4. (A) HYQ, (B) MIT CHEETAH, (C) AND (D) BIGDOG, RESPECTIVELY.

An advanced four-legged robot called (Bigdog) was created by the Boston Dynamics Corporation. [86]. The robot's legs have four degrees of freedom (DOF), and its hydraulic actuators mimic the flexible elements of an animal, efficiently absorbing and releasing moving from one step to the next. It can trot at 0.8 m/s and go across an area that is 35° sloped. *Fig. 4* shows that the robot has a computer on board that has a PC104 Pentium processor and runs a real-time mobile operating system called (Quenix). (BigDog) has fifty sensors built in to help it move. The second generation BigDog was released by the BigDog team in 2008. [32], capable of continuously traveling 130 m without operator intervention, as seen in *Fig. 4*. The project was put on hold, though, because the gasoline-powered engine was making too much noise. The robot was then improved and given the name Legged Squad Support System, which is also known as Alpha Dog *Fig. 4*. It closely resembles its predecessor, BigDog, and is specifically designed for military use, capable of operating in various terrains and environments [87], [88]. Cheetah robot was proposed as a model predictive control framework for a quadrupedal robot to balance on a ball and manipulate it to follow various trajectories. The framework includes a foot placement controller that adapts to a spherical surface. The controller is numerically validated on the Mini Cheetah robot as shown in *Fig. 5* (a) [89] using different gaits including trotting, bounding, and pronking on the ball. Its contribution is fourfold: Dynamic balance controller, multi-contact optimization, trajectory generation, and foot placement controller. Then, a quadrupedal robot called ANYmal as illustrated in *Fig. 5* (b), was introduced which is designed for autonomous operation in challenging environments [90]. The robot features outstanding mobility and dynamic motion capability, thanks to novel, compliant joint modules with integrated electronics. The presented machine was designed with a focus on outdoor suitability, simple maintenance, and user-friendly handling to enable future operation in real-world scenarios. Stoch 2, the latest addition to the Stoch series [91], being a quadruped robot that was independently designed and developed at the Indian Institute of Science in India, as exhibited in *Fig. 5* (c). Weighing around 4 kg and running at 80 MHz, it represents the second generation of the Stoch series [92], [93]. The central module, which serves as a connection between the front and back portions of Stoch 2, houses the controller. In total, the robot boasts 12 actuated degrees-of-freedom. Table I shows some feature comparisons between the existing and proposed robots. This table includes the technology adoption, features, and mechanisms of previous research based on quadruped robots:

FIG. 5. (A) MIT CHEETAH3, (B) ANYMAL, AND (C) STOCH 2.

Received 13/December/2023; Accepted 15/May/2024

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TABLE I. A SUMMARY AND COMPARISON OF THE PERFORMANCE REPORTS THAT HAVE BEEN MADE PUBLIC FOR QUADRUPLED ROBOTS

Robot	Year	Dimension (m) (L _ W _ H)	Weight (kg)	DOF	Pay load (N)	Mechanism of actuator
SCOUT -II	2000	0.55 _ 0.48 _ 0.27	23.7	2	-	Electric
JROB-2	2002	-	29.1	3	-	Electric
BigDog	2005	1.1 _ 0.3 _ 1	109	4	154	Hydraulic
Scalf1	2011	1 _ 0.4 _ 0.68	123	3	80	Hydraulic
Alpha Dog	2012	0.3 (L)	2.85	3	-	Hydraulic
TITAN-XIII	2016	0.21 _ 0.55 _ 0.34	5.65	3	50	Electric
HyQ	2011	1 _ 0.5 _ 0.98	80	3	-	Hydraulic+ Electric
Baby Elephant	2013	1.2 _ 0.6 _ 1	130	3	1000	Hydraulic
AnyMal	2016	-	30	3	100	Electric
qRT-I	2016	1 _ 0.5 _ 1	60	3	400	Hydraulic
Spot	2017	1.1 _ 0.5 _ 0.84	30	3	140	Electric
MIT Cheetah	2018	-	33	2	-	Electric
Stoch 2	2019	-	30	2	-	Electric
IRONDOG MINI	2022	-	2.572	3	-	ELECTRIC

The new challenge and innovation for legged robots are in a physical and simulated scenario of a volcanic eruption. Where, the robots must climb a volcano's escarpment and collect data from areas with high temperatures and toxic gases [94], or develop it to carry out health or hygiene services [95], and some researchers evolved the aspect of artificial intelligence and automatic control [96], [97].

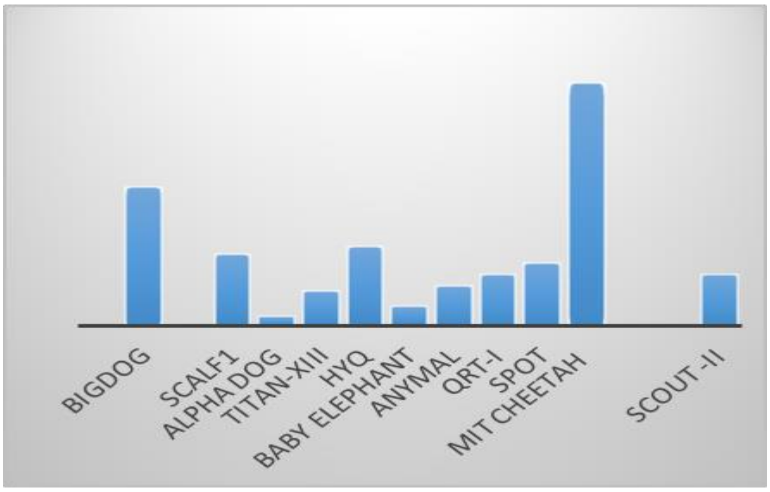

FIG. 6. COMPARATIVE PERFORMANCE OF NORMALIZED SPEED (M/S) AT ROBOT.

Received 13/December/2023; Accepted 15/May/2024
 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

Iraqi Journal of Computers, Communications, Control & Systems Engineering (IJCCCE), Vol. 24, No. 3, September 2024

DOI: https://doi.org/10.33103/uot.ijccce.24.3.1

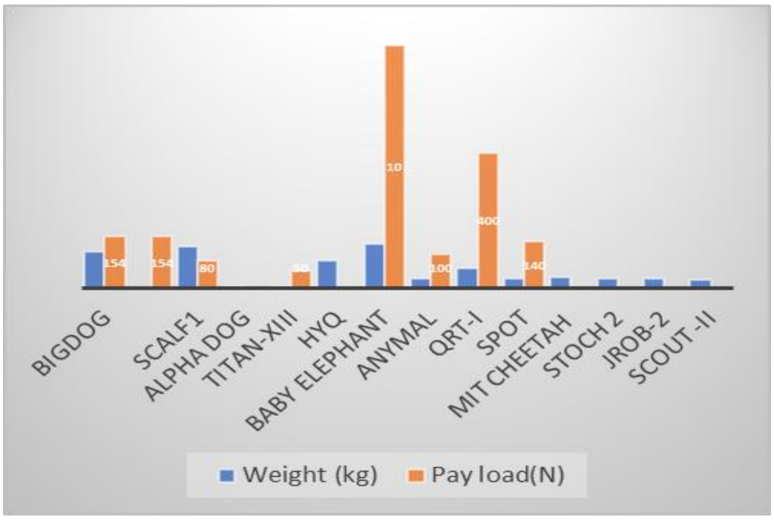

FIG. 7. COMPARATIVE PERFORMANCE OF WEIGHT (KG) AND PAY LOAD (N) AT ALL TYPES OF ROBOTS.

III. DISCUSSION OF THE RESULTS

The movement of mechanical legs involves various dynamic actions, including collision, quick leg swings, and using a lot of force to interact with the terrain. One of the biggest challenges in robotics research has always been designing actuator systems for extremely active legged robots. The key step is selecting the appropriate robot actuator for each joint, considering the leg structure and the number of joints involved. Quadruped robots typically use a single type of actuator, such as electrical, hydraulic, or pneumatic, as displayed at Table I, each having its own advantages and disadvantages. The choice of the most suitable actuator depends on the robot's primary function and requirements. For the HYQ quadruped robot, a hybrid actuation combining hydraulic and electric actuators was used to enhance the robustness and efficiency.

Hydraulic drive quadruped robots, like Scalf and BigDog are designed for outdoor applications, offering large carrying capacity and locomotion capabilities, as manifested in *Fig. 6* and *Fig. 7*, where the BigDog carried payload 154 N and normalized speed 3.5 m/s. But their hydraulic setup adds complexity to the entire structure, where it can be seen that the weight of the BigDog is 109 Kg, while the weight of the Scalf is 123 Kg, as it should be noted that the higher the weight, the higher the cost.

Comparing past quadrupedal robots, it becomes evident that both hydraulic and electrical actuators are frequently employed. While the hydraulic actuators offer a high power-to-weight ratio, they also contribute to the overall weight of the robot [98], [99], [100], [101], [102], [103]. The physical specifications and dimensions play a vital role in determining the mechanical structure design. The choice between a hydraulic or electrical actuation systems directly affects the weight of the robot.

IV. CONCLUSIONS AND FUTURE RESEARCH

This review provides an overview of recent developments in quadruped robots, highlighting several notable systems, such as the BigDog, Spot, MIT Cheetah, Scalf1, HyQ, and ANYmal robots. The development of quadruped robots is being fueled by several key technologies, such as integrated environment perception, high power density actuators, real-

Received 13/December/2023; Accepted 15/May/2024
 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

DOI: https://doi.org/10.33103/uot.ijccce.24.3.1

time control techniques, and innovative biomimetic structures. To build high-performance quadruped robots, each of these components is necessary. Interestingly, this research also explores the fundamental methods used by mobile robots to perceive their surroundings., pay load (N), normalized speed (m/s), and engine mechanism

Looking ahead, the future research directions for the integrated environment perception are as follows:

The review has unveiled new research opportunities and fundamental topics in the field. Despite the significant achievements of robots, like Spot, HyQ, and SCALF, etc., there are several promising areas for future research:

High-level task adaptation: Future robotics should possess the ability to gain experience by regularly performing tasks. Currently, most robots are designed and optimized for specific objectives, necessitating the development of theories that facilitate the "joint evolution" of complex systems to solve real-world environmental problems.

Emerging trends: Artificial intelligence, self-driving cars, networking, teamwork, easy-to-use human-robot interfaces, and expressing and understanding emotions are some of the current trends in robots. These ideas are being used in many areas, like healthcare, business, transporting things, and service robotics.

Challenges in robot applications: Robots can be used for many different things, so there are still problems to solve in terms of controlling their hardware, making software, figuring out how they can fail, and making sure they are safe, reliable, and work well. These things need to be looked into and improved more.

Regarding the bipedal robot, the key conclusions concerning it include:

A- Complexity of the Task: Designing and developing bipedal robots to mimic human walking poses a significant engineering challenge due to the complexity of the walking process and maintaining balance.

B- Core Components: Bipedal robot design involves essential elements such as structure, motors, joints, and sensor systems, which must be comprehensively developed and improved to ensure efficient performance.

C- Programming and Control: The importance of precise programming and control of robots to execute required movements with stability and efficiency during walking is emphasized.

D- Continuous Evolution: Continuous evolution in bipedal robotics is necessary to enhance their performance and adaptability to environmental changes and task requirements.

E- Strategic Importance: The general conclusions underscore the strategic importance of bipedal robots as technological tools with significant potential for developing practical applications in fields such as search and rescue, healthcare, industry, education, and beyond.

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