International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 13 Issue 5 ǁ May 2025 ǁ PP. 21-25

Design and Implementation of a Wheel-Leg Dual-Mode Scalable Biomimetic Mobile Platform

Haolei Zhou[1], Chunyan Zhang[1], Chunlei Jiang[1]
*[*1]School of Mechanical and Automotive Engineering, Shanghai University Of Engineering Science, Shanghai, P.R. China*

Abstract
This paper presents a wheel-leg dual-mode biomimetic mobile platform with morphing capabilities, designed to enhance robotic adaptability in complex terrains. The system integrates three core mechanisms: 1) A disk-type deformation module based on crank-slider principles for width adjustment, 2) A four-bar linkage driven by electric actuators for height variation, and 3) A triangular mode-switching mechanism enabling transition between wheeled and legged locomotion. SolidWorks simulations verify the structural integrity of key components, while motion analysis confirms stable gait transitions. Prototype testing demonstrates successful implementation of morphological adjustments and dual-mode mobility, showing potential for applications in exploration and rescue operations. Compared with conventional designs, this platform achieves simplified control through single-motor driven expansion mechanisms while maintaining structural compactness.

Keywords: *Biomimetic robotics, Morphological adaptation, Wheel-leg transformation, Multi-modal locomotion, Crank-slider mechanism*

Date of Submission: 24-04-2025 Date of acceptance: 04-05-2025

I. INTRODUCTION

The evolution of mobile robotics has highlighted a critical challenge in balancing operational efficiency with environmental adaptability. Conventional wheeled robots, despite their advantages in speed and energy efficiency on structured terrain, exhibit significant limitations when confronted with spatially constrained environments such as narrow gaps below 200 mm or discontinuous obstacles exceeding 40 mm in height. Conversely, legged robotic systems demonstrate superior terrain negotiation capabilities through biologically inspired gait patterns, though their mechanical complexity and high power consumption render them impractical for prolonged field operations.

This research presents an innovative solution through a biomimetic mobile platform integrating three transformative technical features: A crank-slider driven disk mechanism enables dynamic width modulation within a ±100 mm range, allowing traversal of narrow passages previously inaccessible to rigid-frame robots. Complementing this, a four-bar linkage system coupled with electric linear actuators provides 50-70 mm vertical height adjustment, effectively addressing vertical obstacle clearance requirements. The platform's defining innovation lies in its triangular hinge mechanism, which achieves sub-3-second transitions between wheeled rolling and quadrupedal walking modes while maintaining structural integrity through gravity-assisted locking mechanisms.

Prototype validation through SolidWorks motion simulation and physical testing confirms two key operational capabilities: In legged configuration, the platform successfully negotiates 45 mm vertical obstacles through coordinated limb movements, while maintaining a 0.8 m/s rolling speed on paved surfaces when in wheeled mode. The mechanical design draws direct inspiration from canine biomechanical principles, particularly the dynamic weight redistribution observed during quadrupedal gait transitions, translated into engineering solutions through asymmetric linkage configurations.

II. MECHANICAL SYSTEM DESIGN

2.1 Wheel-Leg Structure Design

The deformation of the wheel-leg structure enables the mobile platform to switch between wheeled and legged locomotion modes. By adjusting the vertical height of the wheel-leg mechanism, the overall height of the platform can be modified. This functionality is implemented using the crank-slider mechanism principle shown in Figure 2.1. An electric linear actuator connects the upper and lower legs, enabling leg flexion.

In this design, the electric linear actuators on the wheel-legs primarily control platform locomotion and height adjustment for navigating low-clearance environments. By retracting the actuators, the platform's height can be reduced by 50–70 mm to traverse obstacles without detouring. Since the actuators primarily drive leg lifting (not heavy load-bearing), their selection prioritizes stroke length over force capacity.

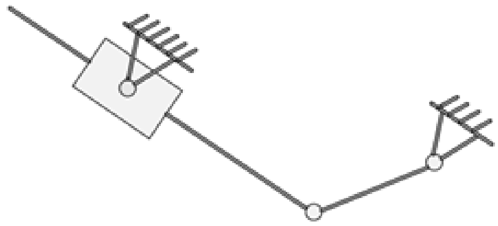
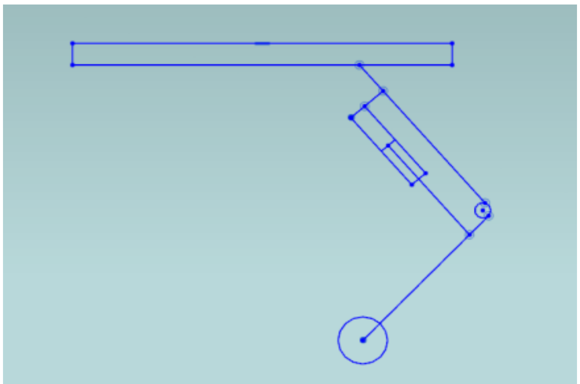
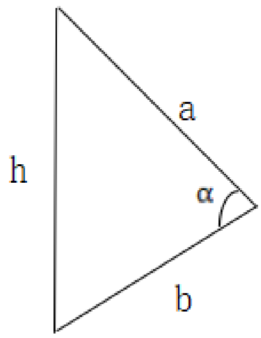


Figure 2.1: The crank-slider mechanism.

As shown in Figure 2.2(a), the platform height h varies with angle α, which is determined by the crank-slider's stroke. Thus, calculating h simplifies to solving the hypotenuse of a triangle (Figure 2.2(b)).

(a) Schematic Diagram of Wheel-Leg Structure. **(b) Comprehensive Simplified Diagram.**
Figure 2.2: Principle Diagram for Calculating Link Lengths in Wheel-Leg Structure.

Using the cosine theorem:

$$h^2 = a^2 + b^2 - 2ab\cos\alpha \quad (1)$$

where a=149.5mm, b=177.2mm. A linear actuator with a 50 mm maximum stroke was selected. For a 40 mm stroke, α decreases from 138° to 74° , theoretically lowering the platform by 65 mm. Figure 2.3 illustrates the single-leg deformable structure model.

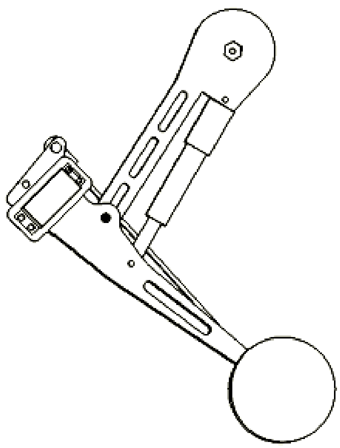
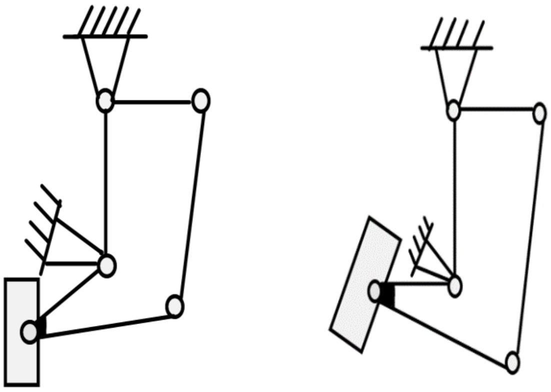


Figure 2.3: Single Wheel-Leg Model Schematic Diagram.

2.2 Wheel-Leg Mode Transition Mechanism

To achieve the wheel-leg mode transition, this design employs a double-rocker mechanism within a four-bar linkage (Figure 2.4). A servo motor is installed at the joint between the lower and upper legs to drive a triangular frame. The servo rotates the triangular frame via a connecting rod linked to the wheel bracket, enabling switching between wheeled mode (Figure 2.4(a)) and legged mode (Figure 2.4(b)). A stepper motor mounted on the triangular frame controls the wheel's rotation speed through a drive disk attached to its output shaft. The optimized mechanism, after kinematic synthesis, is shown in Figure 2.5.



(a) Wheel Structure. (b) leg Structure.

Figure 2.4: Single Leg Wheel-Leg Dual-Mode Transition Principle Structural Schematic Diagram.

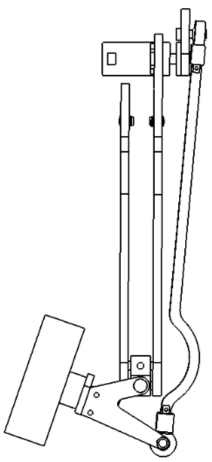
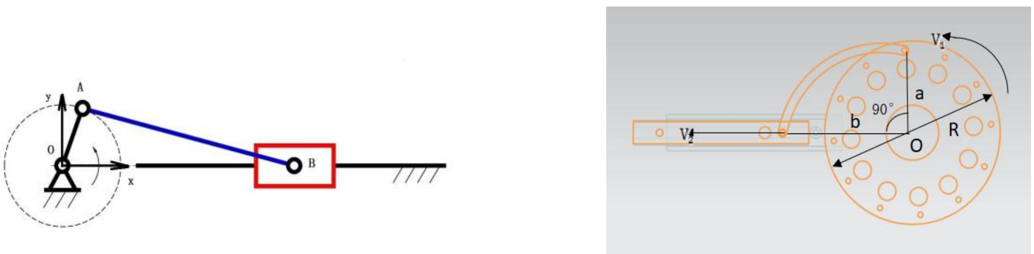


Figure 2.5: Single Leg Wheel-Leg Dual-Mode Transition Model Schematic Diagram.

2.3 Platform Width Adjustment Mechanism Design

The width adjustment mechanism uses a crank-slider mechanism (Figure 2.6(a)). To minimize the number of motors, a central drive disk symmetrically controls two pairs of crank-slider systems (Figure 2.6(b)). The rotation of the drive disk drives curved rods, which are hinged to sliding rails and plate connectors, forming both rotational and translational joints. One disk serves as the load-bearing component, while the other is driven by a motor. For manufacturing simplicity, all rotational joints share identical structural designs.



(a) Crank-Slider Mechanism for Turntable Deformation (b) Calculation Principle Diagram

Figure 2.6: Principle Schematic Diagram of Crank-Slider Mechanism for Turntable Deformation.

Parameters:

a : Radius from the disk center to the curved rod's starting point = 55 mm; b : Distance from the disk center to the curved rod's endpoint; V_1 : Rotational speed of the drive disk; V_2 : Velocity vector of the curved rod's endpoint; R : Disk diameter = 100 mm.

To achieve the target width adjustment, the drive disk rotates 60° . Using the arc length formula:

$$L = \frac{n \times \pi \times r}{180^{\circ}} \tag{2}$$

where n=92°, π≈3.14, r=55mm, the calculated arc length is L=88.269mm. The optimized mechanism is modeled in Figure 2.7.

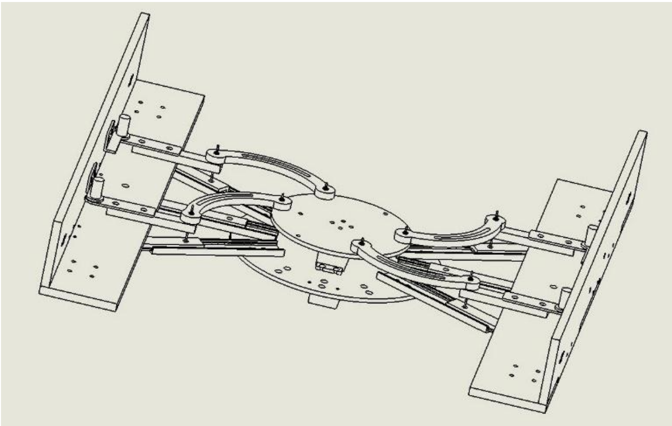


Figure 2.7: Schematic Diagram of Turntable Deformation Mechanism Design Model.

2.4 Selection of Wheel-Leg Drive Motors

The motors available for controlling wheel rotation on the mobile platform include stepper motors, AC motors, and DC motors. After comparing their working principles, characteristics, and control methods, it was found that DC brushed motors require regular maintenance and brush replacement within specified intervals, generate significant noise during operation, and have a shorter service life[1]. Compared to brushed motors, brushless motors have a longer operational lifespan. However, brushless motors generally have smaller overall dimensions and lower current-carrying capacities, resulting in weaker overload tolerance relative to brushed motors. If the platform encounters obstacles or sudden impacts, the drive motor must withstand substantial instantaneous loads, necessitating a motor with strong instantaneous load-bearing capacity. Therefore, brushed DC motors are more suitable for this mobile platform.

Considering factors such as manufacturing costs, control complexity, and size constraints, the platform ultimately adopts DC brushed motors as the driving motors for the wheels.

2.5 Material Selection for Mobile Platform

The material selection for the mobile platform is critical due to strict constraints on size and weight. Even minor differences in material choice for the same component can significantly impact its dimensions, manufacturability, structural integrity, and performance. Therefore, material selection must precede structural and component design. Key considerations for material selection include: Functional requirements, Manufacturability requirements, Economic requirements[2].

The cross-sectional geometry of materials profoundly affects component mass and stiffness. For instance, hollow rectangular sections exhibit five times higher stiffness than hollow circular sections under the same bending moment. Specifically, square tubes demonstrate significantly less deformation, particularly when wall thickness is minimized. Thus, square tubes are adopted as the primary material for the lower segments of the platform's legs[3].

After extensive market research and preliminary testing, hard aluminum alloys—characterized by low density, abundant availability, sufficient strength, and affordability—are selected as the primary material for the platform. LY12 aluminum alloy is used for general components, while high-stress parts such as drive axles employ 45# steel.

2.6 3D Modeling

Building on these material selections and the finalized motor and bearing specifications, the wheel-leg assembly was modeled in SolidWorks as shown in Figure 2.8. The torso deformation mechanism derives its driving force from a motor connected to a push rod, which links the drive turntable (power output shaft) to the platform's upper body. This configuration reduces motor load to prevent burnout and ensures balanced force distribution during parallel telescopic motion. Six linear guides are mounted on the load-bearing turntable at 30° intervals, accommodating the turntable's geometric constraints while maintaining thrust equilibrium. The turntable model (Figure 2.9) incorporates these design parameters.

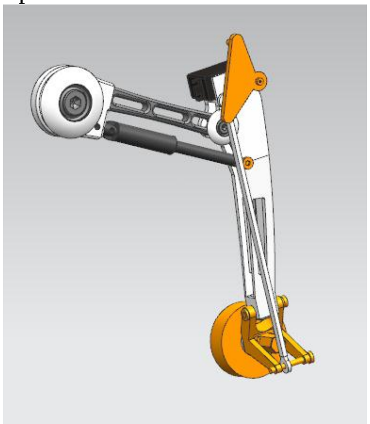


Figure 2.8: Overall Schematic Diagram of the Wheel-Leg Assembly.

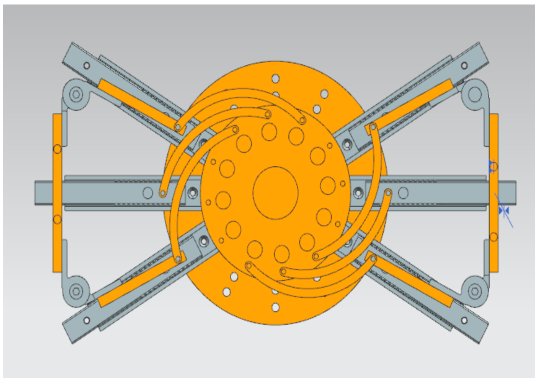


Figure 2.9: Schematic Diagram of the Turntable Deformation Mechanism Model.

2.7 Application Prospects

The wheel-leg bistable telescopic bionic mobile platform can be equipped with modules such as image transmission mechanisms, fire extinguishers, disinfection sprayers, and life detection devices, enabling its transformation into multifunctional robots for exploration, rescue, epidemic prevention, and other tasks. Due to its ability to adjust height, width, and body profile while operating in dual locomotion modes (wheeled and legged), the platform is applicable to fields such as wilderness exploration, mine rescue, highway transportation, and public space disinfection, replacing humans in performing hazardous, load-bearing, and repetitive tasks.

III. CONCLUSION

This study presents the design and implementation of a wheel-leg hybrid mobile platform capable of switching between wheeled and legged locomotion modes while adjusting its width for enhanced adaptability. The mechanical system integrates a crank-slider mechanism for vertical height adjustment, a four-bar linkage for wheel-leg mode transition, and a turntable-driven deformation mechanism for width modulation. Material selection prioritizes lightweight aluminum alloys (LY12) for structural components and high-strength steel (45#) for critical load-bearing parts. DC brushed motors are selected for their instantaneous overload capacity, ensuring reliable performance under sudden impacts. The design demonstrates practical potential for applications requiring both mobility and adaptability in constrained environments.

REFERENCES

[1]. Huang, B., Wang, P. F., & Sun, L. N. (2006). Mechanism design and analysis of a quadruped robot with hybrid locomotion modes. Machine Design and Research, 22(5), 5.
[2]. Guo, L. F., Chen, K., Zhao, D. P., et al. (2009). Research on a wheel-leg reconfigurable mobile robot. *Manufacturing Automation*, (10), 6.
[3]. Yang, Y. D., & Yang, Y. H. (2012). Degree-of-freedom analysis of a novel axial/radial telescopic tire-forming drum mechanism. *China Mechanical Engineering*, 23(22), 6.