A Review of Articulation, Drive, and Track System Technologies for Articulated Tracked Vehicles

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Abstract: Articulated tracked vehicles are amphibious all-terrain platforms capable of operating in complex environments such as snow, swamps, deserts, and mountainous regions. They offer low ground pressure, high terrain adaptability, and superior obstacle-crossing capability, making them widely applicable in both civilian and military fields. This paper presents a review of key technologies for articulated tracked vehicles, focusing on articulation mechanisms, drive system configurations, and track system designs. The structural characteristics and degrees of freedom of typical articulation mechanisms are summarized, highlighting their roles in steering, pitch, and roll control. Different drive configurations, including mechanical and hydraulic systems, are compared in terms of power transmission, compactness, and reliability. Additionally, three representative track system configurations are analyzed with respect to traction performance, ground contact area, approach and departure angles, and amphibious propulsion efficiency. The review indicates that articulation mechanisms and drive systems are critical to overall vehicle performance. Future research should focus on enhancing system reliability, lightweight design, and intelligent control. This study provides a reference for the design and application of articulated tracked vehicles.

Keywords: Articulated Tracked Vehicles; Articulation Mechanism; Drive System Configurations; Track Systems

1. Introduction

The articulated tracked vehicle is an amphibious off-road platform engineered specifically for complex environments. Characterized by low ground pressure, superior terrain adaptability, and high trafficability, ATVs are exceptionally suited for maneuvers in snow, desert, mountains, jungle, and swampland. Consequently, they are widely deployed across polar, mountainous, and wetland regions.

Structurally, an ATV consists of a front unit, an articulation mechanism, and a rear unit, with power delivered to all four tracks. The articulation mechanism is particularly critical, providing three degrees of freedom (DoF): yaw steering, pitch, and roll [1,2]. This mechanism enables active adjustment of the relative steering and pitch angles between the front and rear units while accommodating differential roll angles [3,4]. Compared to single-unit tracked vehicles, the primary mobility advantages of ATVs are as follows:

(1) Enhanced obstacle-crossing capability: By actively modulating the relative pitch angle through the articulation unit, the vehicle can achieve significantly larger approach and departure angles. This active geometric reconfiguration facilitates the negotiation of steep obstacles and uneven terrain;

(2) Superior terrain adaptability and traction: The three-axis DoF allows the tracks to maintain optimal conformity with the ground profile, thereby maximizing the effective contact area and improving soil adhesion. During operation, the “pull-push” interaction between the two units, where one unit assists the other in overcoming resistance, generates substantial tractive force, ensuring mobility in highly variable conditions;

(3) Improved trafficability on soft ground: Active adjustment of the yaw angle enables the vehicle to utilize articulated steering. This method minimizes lateral sliding and steering resistance compared to traditional skid-steering, significantly enhancing performance on soft or yielding substrates;

(4) Increased structural stability: The roll DoF allows the front and rear units to maintain

independent banking angles. This decouples the motion of the two units to a certain extent, effectively mitigating the transmission of torsional loads between the chassis components and enhancing overall vehicle stability during off-road traversal.

2. Key Technology Research Progress

2.1 Articulation Mechanisms

As the primary structural interface of an articulated tracked vehicle (ATV), the articulation mechanism has evolved in close alignment with advancements in multi-body dynamics and off-road locomotion theory [5,6]. Historically, early articulation concepts were adapted from rail locomotives and road trains to resolve the “turning radius paradox,” which refers to the inherent conflict between high payload capacity and maneuverability. However, as operational requirements transitioned to extreme terrains, these mechanisms evolved from passive, single-degree-of-freedom (DoF) linkages into sophisticated, multi-DoF active systems capable of real-time pose modulation.

Articulation mechanisms are categorized into passive-towing and active-adjustment types, depending on their ability to actively modulate the relative pose between the front and rear units.

The primary function of passive-towing articulation mechanisms is to enable the traction of multi-unit bodies and transmit tractive forces. These systems typically comprise mechanical linkages and buffering components connecting adjacent units, yet they lack the capability to actively modulate the vehicle’s pose. A defining characteristic of this type is the provision of a steering DoF, which allows the connected units to rotate around a common vertical axis. This enables differential heading angles, thereby assisting the vehicle in executing turns. Such mechanisms are predominantly applied in road and rail vehicles and exist in various forms, including the kingpins and fifth wheels used in tractor-trailers, as well as railway couplers such as link-and-pin, screw, Janney, and Scharfenberg (tight-lock) couplers.

In contrast, active-adjustment articulation mechanisms are designed to actively modify the pose of the connected units. These systems can transmit both tractive and pose-adjustment forces and are generally composed of mechanical linkages integrated with hydraulic or electric actuators. The hallmark of this category is the ability to enhance terrain adaptability by actively reconfiguring the vehicle’s geometry. Such mechanisms are widely implemented in articulated buses, engineering machinery, multi-unit articulated tracked vehicles, and tandem mobile robots.

Regarding the number of degrees of freedom, the configuration is typically dictated by the vehicle type and its operational environment, with chassis length and terrain complexity serving as the decisive factors. An articulation mechanism may incorporate any combination of steering (yaw), pitch, and roll DoFs. In passive-towing systems, motion in all directions is realized passively. However, in active-adjustment systems, at least one DoF is actuated actively, or a combination of active and passive modes is employed. For instance, the hydraulic articulation turntable of an articulated bus possesses both steering and pitch DoFs; the steering is actively controlled via hydraulic cylinders, whereas the pitch motion remains passive. Similarly, the articulated steering system of a mining truck provides steering and roll DoFs, where steering is active and roll is passive.

Serving as the core structural component connecting the front and rear bodies. It is responsible for transmitting power and control signals, directly governing vehicle maneuverability and terrain adaptability. A typical mechanism incorporates three to five degrees of freedom, primarily utilizing hydraulic cylinders to actuate steering and pitching motions while a rolling swivel seat provides roll capability. The steering hydraulic cylinders generate heading angle deviations and support various operational modes, including locking, active control, and float (passive tracking or follow-up) states. Meanwhile, pitching cylinders are employed to modulate the relative pitch angle between units, enabling rapid adaptation to topographical variations. Finally, the rolling swivel seat permits the chassis to tilt within a defined range, which effectively mitigates the transmission of torsional loads and enhances structural durability during off-road maneuvers.

Figure 1 illustrates the articulation mechanism of the DT-30 [7], which is equipped with two steering and two pitching hydraulic cylinders, yielding three degrees of freedom in steering, pitch, and roll.

The BvS10 articulation mechanism [8−12], shown in Figure 2, differs in that one pitching cylinder is mounted on each body section, affording two independent pitching degrees of freedom and greater flexibility in angular adjustment.

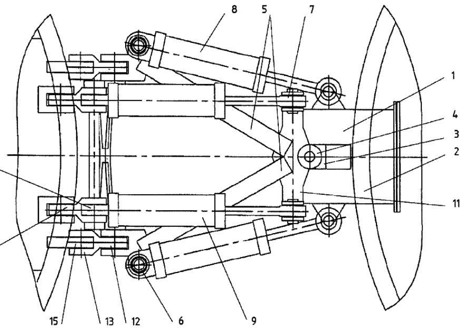


Figure 1. Articulation Mechanism of the DT-30

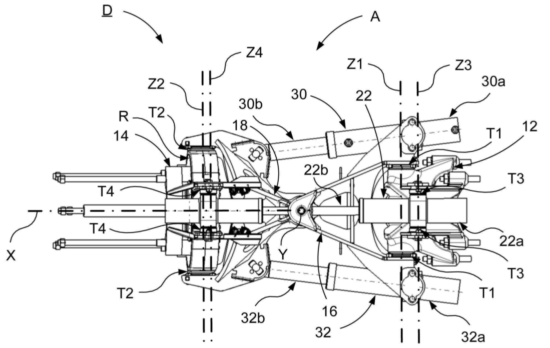


Figure 2. Articulation Mechanism of the BvS10

Figure 3 presents the articulation mechanism of the STK AAV [13], which shares a similar cylinder configuration with the BvS10 but incorporates a coupling-decoupling mechanism at the front body interface, enabling the two sections to be separated and rejoined as needed.

Figures 4(a) and 4(b) depict two articulation mechanisms developed by the Japanese Forest Research Institute. The Type I mechanism in Figure 4(a) features two pitching degrees of freedom and four degrees of freedom in total, while the Type II mechanism in Figure 4(b) provides two degrees of freedom each in pitching and steering, totaling five. Despite their enhanced controllability, the structural complexity of both designs compromises reliability, and neither has achieved widespread adoption.

In summary, articulation mechanisms are primarily designed to connect the front and rear bodies, transmit power and control signals, and facilitate relative motion in steering, pitching, and rolling through active adjustment. A pair of steering hydraulic cylinders generates heading angle deviations with locking, control, and tracking capabilities; one or two pitching cylinders produce pitch angle variation; and the roll connection seat enables passive lateral tilting within a prescribed angular range.

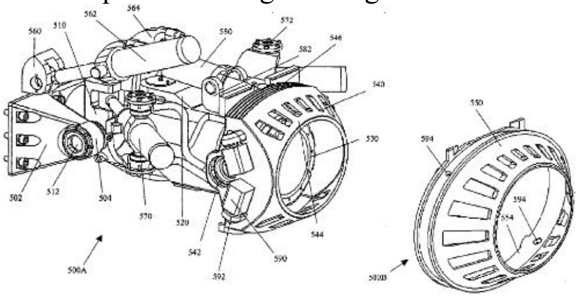
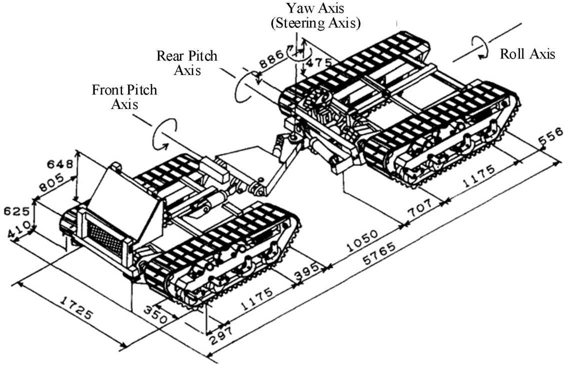
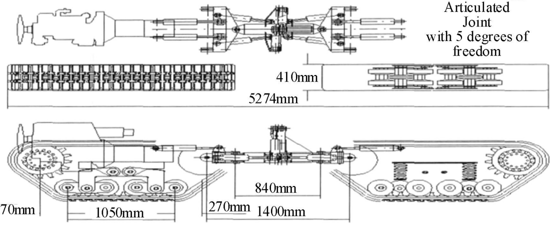


Figure 3. Articulation Mechanism of the AAV



(a) Type I articulation mechanism



(b) Type II articulation mechanism

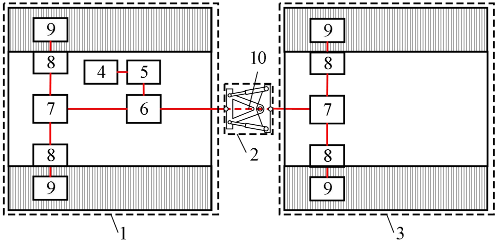
Figure 4. Articulation Mechanisms Developed by the Japanese Forest Research Institute

2.2 Drive System Configurations

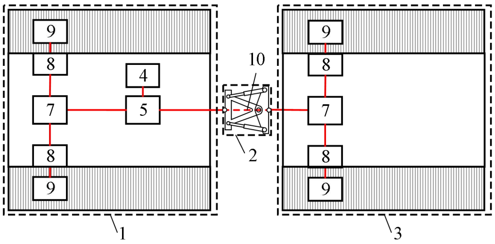
The propulsive architecture of an articulated tracked vehicle is fundamental to its performance as an amphibious, all-terrain platform. Unlike conventional single chassis vehicles, an ATV requires a sophisticated power distribution network to ensure that all four track units remain powered across a range of relative pitch, yaw, and roll angles. The drive system's design must balance mechanical efficiency, spatial constraints, and operational survivability. Based on the configuration of the power units and the method of transmission, four representative schemes are illustrated in Figure 5. Scheme (a) represents a highly integrated approach characterized by a centralized power plant located within the front unit. In this configuration, engine torque is processed through a primary transmission before reaching an inter-axle differential. This differential is critical as it manages the torque split between the front and rear chassis, accommodating the rotational speed differences that arise when the two units traverse uneven obstacles or undergo pitching. Power to the front tracks is distributed through a standard inter-wheel differential and final drive reduction units. Conversely, power for the rear unit must be transmitted across the articulation interface via a telescopic universal driveshaft. This shaft is engineered to accommodate the three-dimensional relative motion between the units. While this scheme maximizes interior volume and ensures equalized tractive effort during steady-state motion, the mechanical complexity of the cross-articulation shaft introduces a significant maintenance burden and a potential point of failure.

Scheme (b) simplifies the architecture by omitting the inter-axle differential. Power is delivered directly from the gearbox to both the front and rear axles. In this rigid or semi-rigid distribution model, the tracks on each side of a given body receive synchronized driving force during steady-state travel. While this design is robust and reduces internal mechanical losses associated with complex differential gears, it can lead to driveline wind-up on high-friction surfaces where minor variations in track slip or effective rolling radii between the front and rear units occur. This configuration is generally optimized for extreme off-road environments where traction is consistently low, such as deep snow or marshland.

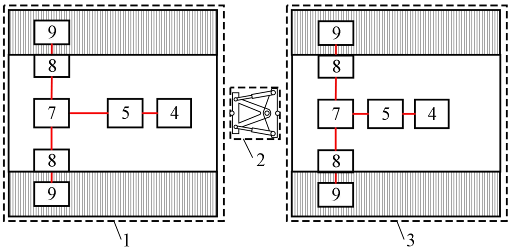
From the perspective of battlefield survivability and modularity, Scheme (c) offers a distinct advantage by utilizing independent power units for both the front and rear bodies. This "redundant" architecture eliminates the need for a high-torque transmission shaft across the articulation joint, which is often the most vulnerable component in a mechanical ATV drive system.



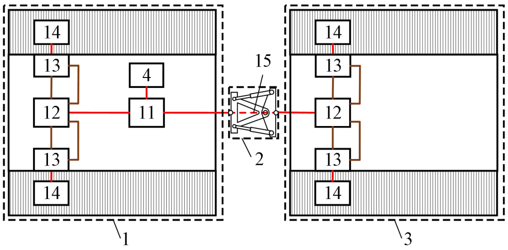
(a) Scheme a: Mechanical drive with inter-axle differential



(b) Scheme b: Mechanical drive without inter-axle differential



(c) Scheme c: Mechanical drive with dual power units



(d) Scheme d: Hydraulic drive

Figure 5. Schematic Illustration of Drive Configurations for Articulated Tracked Vehicles 1−Front Body; 2−Articulation Mechanism; 3−Rear Body; 4−Engine; 5−Transmission; 6−Inter-Axle Differential; 7−Bridge Differential; 8−Reducer; 9−Drive Wheel; 10−Universal Driveshaft; 11−Transfer Case; 12−Variable Pump; 13−Variable Motor; 14−Drive Wheel; 15−Hydraulic Oil Line

In this scenario, if the front engine is disabled, the rear unit can provide sufficient tractive force to recover the vehicle. However, this redundancy comes at a significant cost: the total curb weight of the vehicle increases due to the dual engines, cooling systems, and fuel infrastructures. Furthermore, the dual-engine layout consumes substantial internal volume, potentially reducing the payload capacity or personnel transport space.

Scheme (d) utilizes a hydraulic (hydrostatic) transmission system, which offers the greatest flexibility in layout. An engine in the front body drives high-pressure variable displacement pumps, which transmit energy through flexible hydraulic lines to variable motors located at each drive wheel. The primary advantage of this system is the decoupling of the engine location from the drive wheels; hydraulic hoses can be routed through the articulation joint much more easily than mechanical shafts. Furthermore, hydrostatic drives provide stepless speed regulation and precise torque control, which are vital for low-speed, high-torque obstacle negotiation. Notably, this configuration allows the drive system to share a common hydraulic reservoir and pump assembly with the articulation cylinders, resulting in a more compact and lightweight overall system at equivalent power outputs.

While each of the above schemes offers unique functional benefits, they share a common vulnerability: the reliance on the articulation mechanism for directional control. In current designs, the individual units do not inherently possess independent steering capabilities (such as skid-steering).

Consequently, any catastrophic damage to the articulation joint, whether caused by mechanical fatigue or external impact, renders the vehicle incapable of maneuvering, even if the drive systems remain functional.

The next generation of ATV design may therefore pivot toward a “fully modular” concept. In such a system, each body section would be equipped with an independent power unit and an autonomous steering system. This would allow each unit to function as a self-contained vehicle if separated, truly maximizing the versatility of the articulated platform in the most demanding global environments.

2.3 Track Systems

The track systems of articulated tracked vehicles are engineered specifically for high-mobility operations on soft terrain, with a primary design focus on weight reduction, expansive ground contact area, and minimized ground pressure. As visually synthesized in Figure 6, the evolution of these systems reveals a distinct technical trade-off between mechanical traction and amphibious versatility. While traditional designs prioritize aggressive soil-shearing capabilities, modern configurations increasingly lean towards modularity and hydrodynamic efficiency to suit multi-modal mission requirements. The strategic positioning of drive and idler wheels, combined with varied track profiles, allows for tailored approach and departure angles that directly influence obstacle-negotiation performance. This technical divergence indicates that track system design is a specialized adaptation to specific operational theaters rather than a universal solution. Currently, three mainstream configurations represent the state-of-the-art in articulated tracked vehicle technology, each offering unique advantages in traction and terrain adaptability.

Scheme 1, exemplified by the DT-30, uses a combination of rubber ring bands and metal spikes, forming an inverted trapezoidal track profile with front-mounted drive wheels that provide a large approach angle. The suspension system employs longitudinal torsion bar springs integrated into the vehicle body; road wheels are connected via swing arms and fitted with polyurethane tires. An idler wheel at the rear of the track assembly incorporates a tensioning mechanism. The metal spike design substantially increases traction relative to comparable ground contact area and pressure conditions.

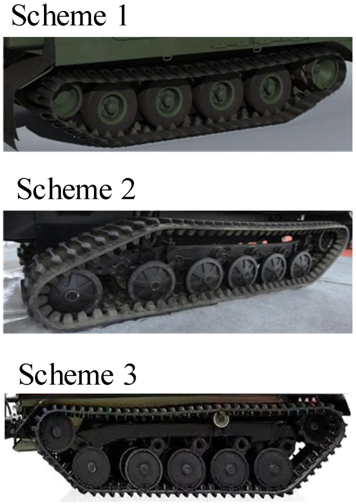


Figure 6. Comparison of Track System Configurations

Scheme 2, represented by the BvS10, features a one-piece rubber track with fish-scale spikes in a parallelogram profile. Front-mounted drive wheels are equipped with dual guide teeth, and the suspension system uses rubber torsion springs with road wheels mounted on rubber-bushed swing arms and arranged in paired rubber-tired sets. The rear idler wheel carries partial load in addition to maintaining track tension. This configuration achieves the largest ground contact area among the three schemes, and the fish-scale spike geometry improves water propulsion efficiency. All four track assemblies are modularly interchangeable, facilitating maintenance and adaptability.

Scheme 3, as seen in the GAZ-3344, closely resembles Scheme 2 in general architecture but employs an inverted trapezoidal track profile with an adjusted idler wheel position to achieve a larger departure angle. Suspension, road wheels, and tensioning devices follow the same design as Scheme 2. Water propulsion efficiency remains high, and modular interchangeability is retained.

Beyond geometric profiles, the selection of suspension systems and track materials significantly influences the dynamic stability of these configurations. Scheme 1 utilizes longitudinal torsion bar springs, which offer substantial travel and high durability for heavy-duty traversal of steep obstacles. In contrast, the rubber torsion springs and rubber-bushed swing arms employed in Schemes 2 and 3 prioritize high-frequency vibration damping and noise reduction, which are critical for long-distance transit and crew comfort. Furthermore, the transition from metal-reinforced spikes to one-piece rubber tracks reflects a shift toward multi-modal operational requirements. While metal spikes provide unmatched soil-shearing capability in icy or marshy terrains, modern one-piece rubber tracks offer more uniform pressure distribution and lower rolling resistance. This evolution indicates a design trend toward balancing extreme off-road traction with high-speed road mobility and amphibious efficiency, ensuring that the vehicle maintains performance when transitioning between terrestrial and aquatic environments.

The three schemes differ meaningfully in key performance metrics. Scheme 1 delivers the highest traction owing to its metal spikes and offers a large approach angle through its inverted trapezoidal profile and front drive-wheel placement. Scheme 2 achieves the greatest ground contact area and the highest water propulsion efficiency; certain variants additionally incorporate cylindrical shock absorbers to reduce obstacle-crossing impact loads and extend rubber suspension service life. Scheme 3 inherits the one-piece rubber track and modular design of Scheme 2 while prioritizing a larger departure angle through its track geometry and idler positioning. In brief, Scheme 1 excels in traction, Scheme 2 in ground coverage and amphibious performance, and Scheme 3 in departure angle capability and ease of maintenance.

3. Conclusion

Articulated tracked vehicles achieve exceptional mobility, traction, and stability across complex terrain through the coordinated optimization of articulation mechanisms, drive systems, and track configurations. The degree-of-freedom arrangement and hydraulic layout of the articulation mechanism fundamentally determine vehicle maneuverability and terrain adaptability, while the choice of drive system governs space utilization and operational resilience. Track system configuration, in turn, governs traction capacity, ground contact area, and departure angle performance. Future research should prioritize enhancing the reliability of articulation mechanisms and drive systems. Additionally, advancing lightweight track design and integrating intelligent control strategies with modular system architectures to further improve obstacle-crossing capability and adaptability to complex terrain conditions.

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