Final Written Report

1. Background

1.1 Research Background and Significance

Current robotic systems with single locomotion modes exhibit notable limitations in complex environments. While quadrupedal robots demonstrate superior flexibility and terrain adaptability, their mobility on flat surfaces remains suboptimal. Conversely, tracked robots offer enhanced speed and stability but underperform in rugged terrains. To address these constraints, this study proposes a transformable quadrupedal-tracked hybrid robot, integrating the advantages of both modalities. As an innovative advancement in robotics, this design holds potential to redefine operational boundaries, enhance performance in unstructured environments, and drive technological progress across diverse application domains.

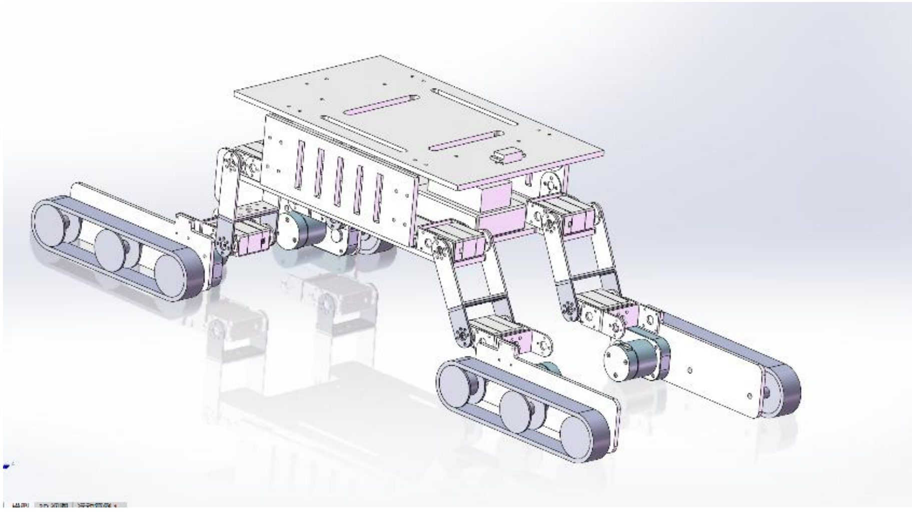
1.2 Application Scenarios

The quadrupedal transformable tracked robot boasts extensive application prospects. In disaster rescue, it can swiftly navigate complex terrains such as earthquake rubble and mudslide sites, maneuvering through obstacles to search for survivors with life-detection equipment. For industrial inspections, it accesses intricate factory areas to closely examine pipelines and machinery, identifying potential hazards. In confined space exploration—such as underground caves or urban pipelines—its compact, agile, and stable design ensures effective mission completion.

2.Design Of The Robot

2.1 Brief Function Description

The robot exhibits several prominent features. Its core innovation lies in the hybrid wheel-leg design: on flat terrain, the tracks enable rapid movement, outperforming traditional quadruped robots; on rugged terrain, the legs provide flexible posture adjustment, significantly enhancing traversability compared to conventional tracked robots. Equipped with attitude sensors, it monitors posture in real-time and promptly corrects anomalies to prevent tipping. The centrally mounted LiDAR not only generates basic terrain models for operational planning but also reduces collision risks due to its protected placement. Additionally, the robot features adjustable track width and center-of-mass positioning, further optimizing adaptability to diverse terrains and task requirements.



2.2 Core Innovation Point

The core breakthrough of this robot lies in its **"quadruped-tracked" dynamic hybrid locomotion mechanism**, which overcomes the limitations of traditional single-mode robots and achieves efficient, stable movement in complex terrains. Its innovations are primarily reflected in the following aspects:

(1) **Intelligent Dual-Mode Switching**

Tracked Mode (High Speed & Stability): On flat or low-obstacle terrain, the robot adopts tracked propulsion, significantly outperforming traditional quadruped robots (e.g., Boston Dynamics Spot) in speed while maintaining the load-bearing capacity and stability of tracked structures.

Quadruped Mode (High Traversability): When encountering rugged terrains such as steep slopes or debris, it switches to a quadrupedal gait, adjusting posture through joint degrees of freedom to overcome obstacles (e.g., steps, ditches) that are impassable for conventional tracked robots.

(2) **Dynamic Coupling Control**

Kinematic Coordination Algorithm: Based on the Denavit-Hartenberg (D-H) parameter method, an inverse kinematics model for the quadruped mode is established, combined with the dynamics of track slippage ($v = \omega \cdot r \cdot (1 - \eta)$). The output velocities of the two modes are dynamically adjusted via parameter α ($v_{total} = \alpha v_{leg} + (1 - \alpha) v_{track}$) to ensure smooth transitions.

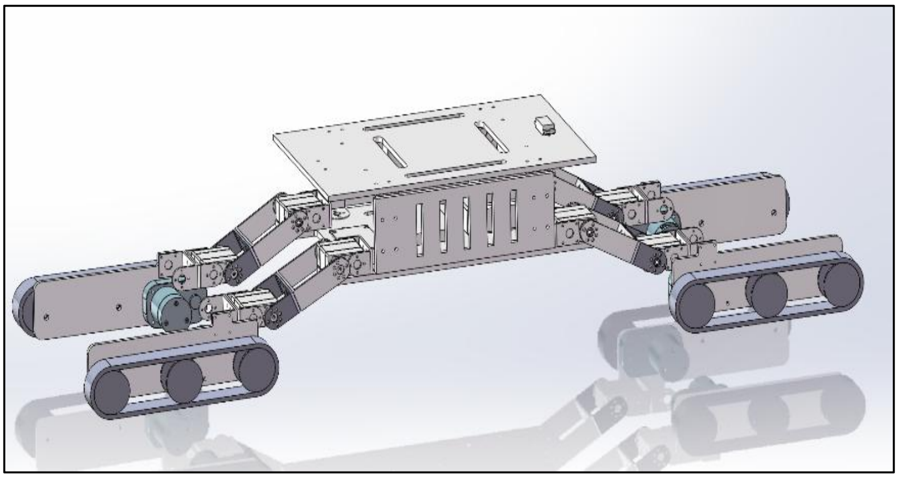
ZMP Stability Optimization: The Zero Moment Point (ZMP) theory is employed to monitor the center of mass (CoM) projection in real-time, ensuring dynamic balance during mode switching and preventing tipping (e.g., during obstacle crossing, the CoM must satisfy $x_{CoM} \geq H + l_{base}/2$).

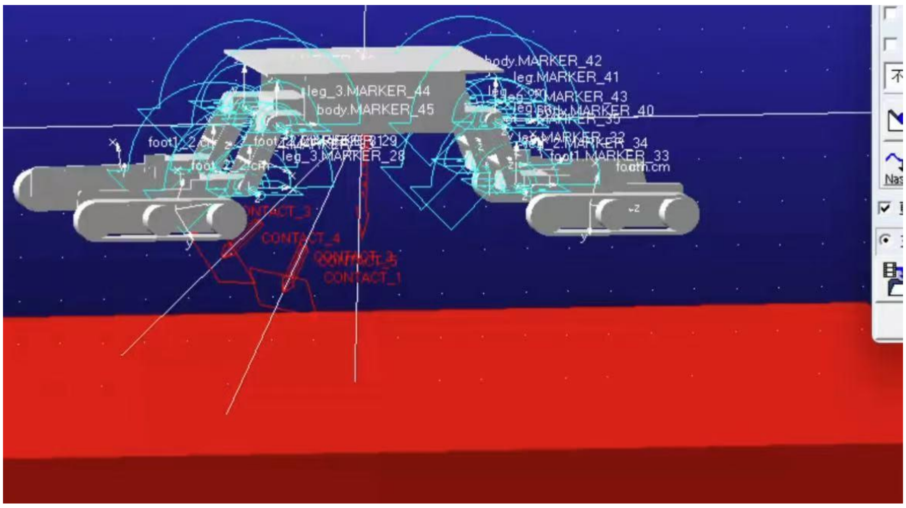
(3) **Adaptive Mechanical Design**

Adjustable Track Width: The track spacing can be mechanically modified to adapt to confined spaces (e.g., pipelines) or loose surfaces (e.g., sand).
Active CoM Adjustment: Combined with IMU data, the robot dynamically adjusts its posture to enhance stability during slope climbing or obstacle traversal.

Technical Advantages:

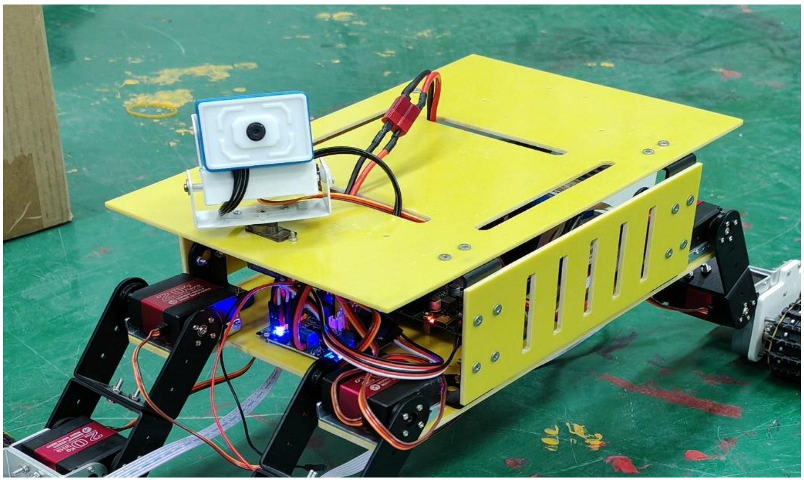
- **Speed and Traversability Combined**: Tracked mode increases speed by over 30%, while quadruped mode doubles the obstacle-crossing height of conventional tracked robots.
- **Autonomous Decision-Making**: Multi-sensor feedback (LiDAR, IMU) enables automatic selection of the optimal locomotion mode, minimizing human intervention.





3. Procedure

3.1 Design of the Body Materials



Main material: 3240 epoxy resin board (yellow part shown in the figure above)

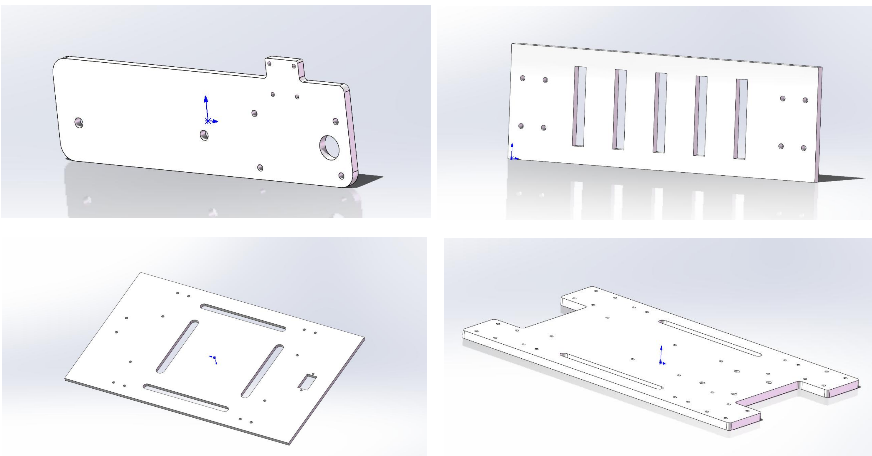
Material Advantages:

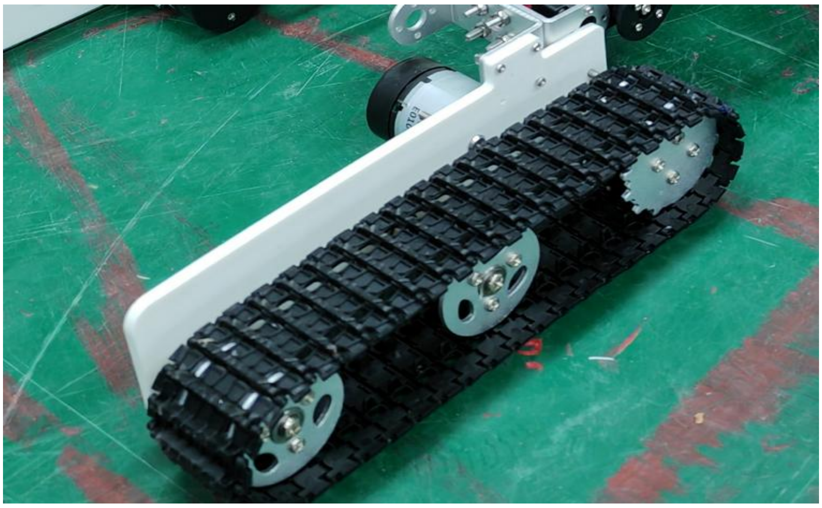
1.High Strength and Rigidity:

The tensile strength (≥300 MPa) and flexural strength (≥350 MPa) of 3240 epoxy boards significantly surpass those of common engineering plastics (e.g., ABS/PLA at 50-80 MPa), approaching the range of aluminum alloys (tensile strength ~200-600 MPa) while offering lower density (1.8-2.0 g/cm³). This makes them ideal for tracked robots operating under impact- and torsion-prone conditions (e.g., obstacle traversal or load-bearing movement).

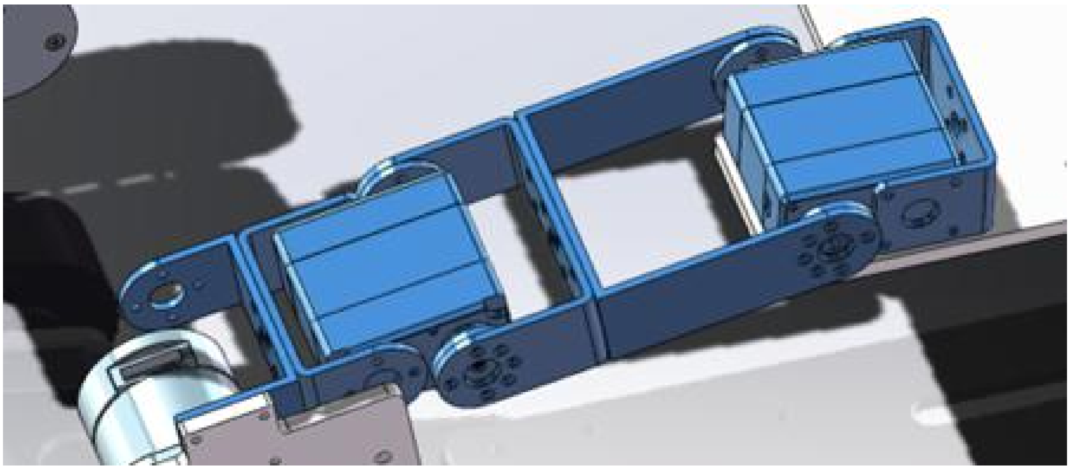
2.Interlayer Bonding Strength:

The glass fiber laminate structure, formed via high-temperature and high-pressure processes, eliminates the risk of interlayer delamination inherent in 3D-printed materials, ensuring long-term reliability.





3.2 Design of the Leg



Design Advantages:

1. Modularity Benefits

Cost Efficiency: Modular design reduces manufacturing costs by enabling the reuse of identical modules across multiple robots or different components.
Rapid Development: Accelerates prototyping and testing by allowing quick assembly of different modules.

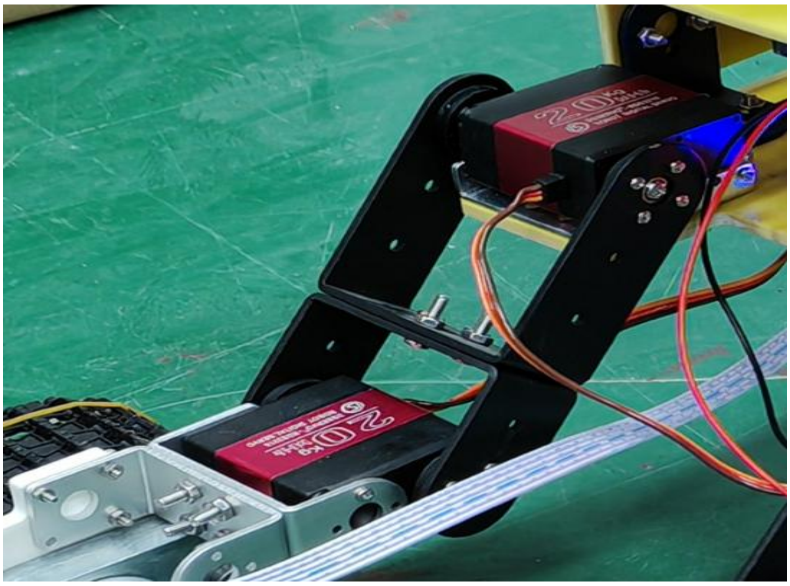
2. Lightweight Advantages
Enhanced Performance: Improves mobility and agility, enabling faster movement and more flexible operation.

Reduced Power Consumption: Critical for battery-powered robots, extending operational duration and battery life.

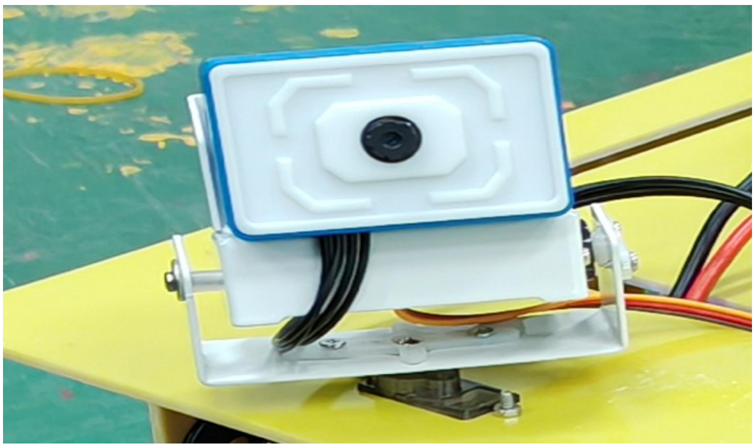
3. High-Strength Advantages

Reliability: Ensures consistent performance in diverse environments, minimizing failures and downtime.

Adaptability: Expands applicability to demanding conditions, including harsh operational scenarios.



3.3 2-DOF Pan-tilt Servo



Core Functions and Capabilities

1. Dynamic Environment Perception & Monitoring

"Multi-Angle Field Coverage"

Equipped with a 2-DOF gimbal (±90° pitch, ±180° yaw), the robot dynamically adjusts camera angles during movement, eliminating blind spots inherent in fixed cameras. Ideal for full-range surveillance in complex terrains (e.g., slopes, obstacles).

"Stable Image Transmission"

Delivers real-time 1080P/60fps HD video via Wi-Fi/4G/5G with low latency (<200ms), enabling remote monitoring for search & rescue, security, and other critical applications.

2. Intelligent Recognition & Interaction

"Face Recognition"

Leveraging deep learning, it detects and identifies individuals in real time for:

Security Patrols: Auto-alerts for unauthorized personnel.

Human-Robot Interaction: Unlocks permissions via operator identification.

"QR Code Recognition"

Rapidly scans QR tags to facilitate:

Industrial Inspections: Auto-generates reports by reading equipment data.

Logistics Sorting: Guides cargo handling via encoded identification.

"Color Recognition"

Analyzes HSV color space to detect specific markers, enabling:

Path Tracking: Follows colored ground guides.

Target Localization: Identifies objects like red hydrants or yellow hazard zones.

3.4 Software

Electronic Control System

STM32-based motion control of a transformable tracked quadruped robot with PS2 wireless remote, featuring:

PS2 wireless remote control

Four-wheel motor drive (forward/reverse/steering with continuous speed control)

Eight-DOF robotic leg servo control

Two-DOF camera gimbal control."

4. Benefits and Applications

4.1 Application Scenarios

4.1.1 Search and Rescue Operations

In disaster rescue scenarios, the transformable quadruped-tracked robot demonstrates significant advantages. After earthquakes, collapsed urban structures create complex rubble environments filled with obstacles and unstable terrain, where conventional rescue equipment struggles to operate. This robot, leveraging its quadrupedal climbing agility and tracked stability, can navigate through debris while utilizing onboard life detectors and thermal imaging cameras to accurately locate trapped survivors. This capability enhances rescue efficiency, providing critical information to save more lives.

4.1.2 Confined Space Operations

For operations in narrow and hazardous environments—such as urban underground pipelines or mines—manual inspection and maintenance pose high risks and challenges. The transformable quadruped-tracked robot adapts to tight spaces by adjusting track width and center-of-mass posture, enabling efficient pipeline inspection and maintenance. It can detect leaks, cracks, and other structural issues, ensuring infrastructure safety while minimizing human exposure to dangerous conditions and reducing accident risks.

4.2 Social Value

The deployment of transformable quadruped-tracked robots holds significant social value. In disaster response, they reduce first responder casualties and improve rescue success rates, safeguarding lives. In industrial and infrastructure maintenance, they enhance operational efficiency, reduce labor intensity, and improve workplace safety, contributing to societal stability and development.

4.3 Economic Value

From an economic perspective, transformable quadruped-tracked robots have broad market potential. In industrial applications, they lower production costs, improve product quality and efficiency, and strengthen corporate competitiveness. As technology matures and demand grows, expanded production scales will drive synergistic growth in related industries—such as component manufacturing and software development—forming a robust industrial chain and generating substantial economic benefits.

5. Summarize

5.1 Project Summary
The transformable quadruped-tracked robot project aims to integrate the advantages of legged and tracked robotics to address complex environment operations. Through in-depth research and continuous optimization of mechanical structures and control systems, significant progress has been made in vehicle design and software control, including 3D modeling, preliminary assembly, and basic PS2 remote control over motors and servos. Key challenges—such as software control errors, multi-servo coordination, and chassis reinforcement—were identified and resolved, laying a solid foundation for future development.

5.2 Future Work
Future research will focus on:
Hardware: Optimizing mechanical structures, designing reinforced top panels and enclosures for sensor integration, and improving shock resistance and durability.
Software: Implementing a dedicated servo control board, refining PID algorithms for higher servo precision, and incorporating vision-based functions (e.g., face recognition and obstacle detection) to enhance autonomy and operational capability.
As the technology matures, this robot is expected to expand its applications across diverse fields, contributing to both societal progress and economic growth.

6. Acknowledge

- The professors who offer us many practical recommendations.
- The students who make contributionsto this project.
- The company which assisted usto make 3D-Printing mechanisms.
- The robot laboratory which offer ustechnologicalsupport.