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UNMANNED GROUND VEHICLE ARCHITECTURE AND OPERATIONAL PRINCIPLES

Annotation. *This paper presents the architecture and operational workflow of an unmanned ground vehicle (UGV) based on a conventional military truck platform. The system integrates modular electronics, layered autonomy, and secure tele-operation, combining high-level mission logic with real-time electromechanical control for reliable defense-grade UGV deployment.*

Keywords: *autonomous vehicle; tele-operation; military UGV; layered control; sensor fusion; actuator system*

Анотація. *У роботі подано архітектуру та принципи роботи безпілотної наземної транспортного засобу (БНТЗ), побудованого на базі традиційної військової вантажівки. Система використовує модульну електроніку, багаторівневу автономію та захищене дистанційне керування, поєднуючи завдання на управління з реальним часом електромеханічного контролю.*

Ключові слова: *автономний транспортний засіб; дистанційне керування; військовий БНТЗ; багаторівневий контроль; сенсорна інтеграція; система приводів.*

Introduction. Uncrewed Ground Vehicles (UGVs) have rapidly evolved, particularly in military logistics, reconnaissance, and engineering support. Two principal design philosophies can be identified. *The first* is the development of a ground vehicle based on a custom chassis with hub motors and integrated electronic architecture, similar to modern electric robotic platforms. *The second* approach is the conversion of a conventional heavy-duty truck into a remotely-controlled or autonomous vehicle. This work addresses the second path and describes the architecture and operating principles of a driverless system implemented on a heavy military truck platform.

The UGV based on an electric modular chassis with hub motors provides notable advantages: inherently digital control, high vehicle responsiveness, distributed torque control, reduced mechanical wear, improved maneuverability, and simplified integration of autonomous algorithms. These systems, however, require expensive components, specialized manufacturing capabilities, rugged traction batteries, advanced cooling systems, and robust “electromagnetic interference / electromagnetic pulse” protection. Development cycles are long, supply chains exposed, and field maintenance complex. Such platforms are optimal for long-term mass adoption programs but less suitable for urgent wartime deployment.

In contrast, converting a traditional internal-combustion army truck offers rapid field introduction, compatibility with existing fleets, simplified logistics, and low training overhead for mechanics. Fuel systems, spare parts, and repair expertise are already available in military units. The disadvantages include legacy mechanical and hydraulic systems not originally intended for automation, slower response time compared to electric drive, limited control resolution, and additional electromechanical actuators required for steering, throttle, brake and gear control. Nevertheless, the conventional-truck approach allows rapid prototyping, cost efficiency, rugged operation, and real-world battlefield deployment.

This paper presents the high-level architecture (“static view”) and operational workflow (“dynamic view”) of the driverless truck conversion, reflecting modular hardware integration, command and telemetry flows, and cost-driven engineering trade-offs. The text is intended as an introductory briefing for electromechanical engineers and acts as a gateway to full technical documentation, control algorithms, and wiring schematics.

Static Architecture (Block Diagram Explanation). The system contains 11 functional blocks, representing command source, communication interface, computational units, sensor suite, and actuator chain (Table 1).

This architecture separates mission-level logic, real-time control, and hardware drive electronics, conforming to layered autonomy and safety standards used in defense/industrial robotics. In other words, this design cleanly separates high-level mission planning, real-time motion

Table 1 – Main functional characteristics of the UGV

Block	Name	Function
1	Operator HMI	Remote human-machine interface: laptop, radio panel, situational display, joystick. Generates movement commands, receives telemetry and safety status.
2	Cab I/O Controller (STM32/Teensy)	Low-level signal conditioning, command serialization, hardware watchdog. Converts operator input to command packets.
3	Radio Transmitter Modem (RFD900 / LTE)	Primary RF link or LTE tunnel for command transfer. Ensures secure low-latency communication.
4	Vehicle Communication Gateway	Entry point on vehicle. Handles cryptography, routing, and safety validation of incoming commands.
5	High-Level Controller (NVIDIA Jetson / IPC)	Mission computer running ROS2; performs sensor fusion, high-level plan execution, object detection (AI).
6	Autonomy Middleware	Real-time ROS2 bridge layer: navigation stack, motion planning, and middleware communication.
7	Real-Time Controller (PX4 / ECU)	Deterministic control layer, closed-loop stabilization, PID loops, actuator safety guards.
8	Sensor Suite	GNSS-RTK, IMU, wheel encoders, cameras, optional LiDAR. Provides vehicle state and environment feedback.
9	Actuator Controllers (Roboteq / ODrive)	Motor drivers for steering motor, brake servo drive, throttle actuator. Current sensing & safety cut-off.
10	Sensor Bus (CAN/UART/I2C)	Unified communication backbone for sensor fusion and coordination between compute modules.
11	Physical Actuators	Steering actuator, brake and throttle drives, transmission linkage servo, relay valves, ignition and fuel control.

control, and low-level actuator electronics, following layered safety and autonomy practices used in military and industrial robots. So, this is the so-called hierarchical control principle (Table 2).

Table 2 – The UGV system levels characteristics

Layer	Meaning	Example
Mission-level logic	High-level decisions, task planning	“Go to GPS point and avoid obstacles”
Real-time control	Control loops, stabilization	PID loops for steering / throttle
Hardware drive electronics	Physical motor control	Motor drivers, actuators, power stages

Dynamic operation command flow includes the following: 1. Operator issues motion command via HMI (Block 1). 2. Cab controller (Block 2) digitizes command, applies rate limits and safety filters. 3. Radio modem (Block 3) transmits packet over encrypted channel. 4. Vehicle communication gateway (Block 4) authenticates message, rejects anomalies. 5. High-level controller (Block 5) interprets task, updates mission context (waypoints, targeting, or tele-operation). 6. Middleware (Block 6) computes desired trajectory and control targets. 7. Real-time controller (Block 7) executes low-latency control loops. 8. Actuator drivers (Block 9) deliver adjustable power to actuators. 9. Mechanical actuators (Block 11) manipulate steering, brake, throttle and drivetrain linkages.

Dynamic operation telemetry flow includes: 1. Sensors (Block 8) continuously measure motion and environment. 2. Sensor data passes through unified bus (Block 10). 3. RT controller and HLC fuse sensor data (Blocks 7 and 5). 4. Gateway (Block 4) sends telemetry packet. 5. Radio modem (Block 3) transmits data to operator station. 6. HMI (Block 1) displays vehicle state, alarms, video feed.

Safety behavior is insured by: 1. Loss of link triggers fail-safe stop. 2. Direct bypass path exists 4 → 7 for ultra-low-latency control in tele-operation. 3. Actuator chain includes hardware current limits and emergency power-off paths. The system therefore balances autonomy, tele-operation, and field maintainability, ensuring resilience in contested environments.

Modular structure allows field replacement, incremental upgrades, and fleet standardization. Sensors and controllers can be swapped without major architectural change, supporting flexible mission profiles.

Cost Considerations (BOM Overview). The bill-of-materials (BOM) emphasizes commercially available and defense-grade components. Estimated cost structure (indicative) is given in Table 3.

Table 3 – Cost considerations overview

Category	Approx. share
Computing hardware (Jetson, MCU stack)	30–35%
Communications and security modules	10–15%
Actuators and drive electronics	25–30%
Sensors and RTK navigation	20–25%
Aux cabling, mounting, and fabrication	5–10%

Compared to dedicated UGV chassis, the primary cost savings arise from: 1) reuse of existing truck platform and drivetrain; 2) absence of high-energy traction batteries; 3) simplified logistics and maintenance.

The resulting configuration is a cost-effective deployment pathway for field-ready military UGVs requiring reliable tele-operation and assisted autonomy.

Conclusion. The described truck-based UGV represents an effective transitional model between legacy military vehicles and fully electric modular ground robots. It leverages available parts, robust mechanical structure, and proven reliability, while enabling modern autonomous control methods via modular electromechanical integration. Such architecture enables rapid scaling, flexible roles (logistics, CASEVAC, sapper support, reconnaissance), and future upgrades toward higher autonomy levels, supporting current battlefield requirements and reducing personnel exposure. The range of UGV products can be quite wide, including construction-and-road equipment (excavators, etc.). As UGV technology advances, autonomous platforms will support infantry by performing key engineering tasks, including trench excavation.

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