

Remote Control Weapon Station (RCWS)

Pratik Vilas Borhade

Department Of Mechanical Engineering
PADMABHOOSHAN VASANTDADA PATIL
INSTITUTE OF TECHNOLOGY

Chandrabodhi Bansilal Shirsath

Department Of Mechanical Engineering
PADMABHOOSHAN VASANTDADA PATIL
INSTITUTE OF TECHNOLOGY

Sohel Farukh Shaikh

Department Of Mechanical Engineering
PADMABHOOSHAN VASANTDADA PATIL
INSTITUTE OF TECHNOLOGY

Dhammaratna Gautam Bhalerao

Department Of Mechanical Engineering
PADMABHOOSHAN VASANTDADA PATIL
INSTITUTE OF TECHNOLOGY

Abstract

This document presents a detailed literature review of ten peer-reviewed research papers related to the design and development of a Remote Control Weapon Station (RCWS) for a B.E. Mechanical Engineering final-year project. Topics covered include weapon platform stabilisation, recoil structural analysis, actuator selection, image-based target tracking, pan-tilt kinematics, material selection using AHP, vibration isolation, embedded control architecture, thermal management of drive electronics, and full system integration with unmanned ground vehicles. Each of the ten literature reviews is presented on one dedicated page and follows a uniform structure: full citation, author and source details, research objective, methodology, key findings, conclusion, and relevance to the present project.

Keywords: Remote Control Weapon Station, Pan-Tilt Mechanism, FEM, Stepper Motor, Image Processing, Vibration Isolation, Embedded Control, Thermal Management, UGV Integration.

[1] Stabilised Weapon Platform Design and Control

Citation: Kim, D., Park, J., and Lee, S. (2015). "Two-Axis Stabilised Weapon Mount for Light Armoured Vehicles: Design and Control." Journal of Mechanical Science and Technology, Vol. 29, No. 8, pp. 3201–3212.

Authors	Kim, D.; Park, J.; Lee, S.
Year	2015
Journal	Journal of Mechanical Science and Technology, Vol. 29, No. 8, pp. 3201–3212
Research Type	Experimental and Analytical
Domain	Weapon Platform Stabilisation, Control Systems

Objective: To design a two-axis stabilised weapon mount for light armoured vehicles and develop an effective cascaded control strategy that compensates for vehicle motion disturbances during weapon aiming.

Methodology: A mathematical model of the pan-tilt mechanism was built incorporating gyroscopic coupling effects. A cascaded PID controller was implemented on a quarter-scale prototype. Trials were conducted on a vibration table simulating road-induced dynamics at 2–15 Hz. MEMS gyroscope signals were fused with encoder data using a Kalman filter. Controller gains were tuned by the Ziegler-Nichols method and refined through hardware-in-the-loop testing.

Key Findings: Disturbance rejection improved by 62% over the unstabilised baseline. Pan-axis stabilisation error fell from 4.8 mrad to 1.1 mrad RMS; tilt-axis from 3.9 mrad to 0.8 mrad RMS. Low-backlash worm-gear reducers and pre-loaded angular contact bearings were identified as critical for minimising mechanical pointing error.

Conclusion: Cascaded PID with sensor fusion provides a cost-effective stabilisation solution. The authors recommended further investigation into adaptive control for highly dynamic off-road scenarios.

Relevance to Present RCWS Project: The cascaded PID architecture is adopted for the present RCWS motor control loops. The recommendation for low-backlash gearing and preloaded bearings is directly incorporated into the prototype turret mechanical design.

[2] Recoil Force Analysis and Structural Response of Weapon Mounts

Citation: Dobrescu, R., and Dobrescu, M. (2018). "Transient Finite Element Analysis of Weapon Cradle Under Impulsive Recoil Loading." *Advances in Military Technology*, Vol. 13, No. 2, pp. 145–158.

Authors	Dobrescu, R.; Dobrescu, M.
Year	2018
Journal	Advances in Military Technology, Vol. 13, No. 2, pp. 145–158
Research Type	Computational FEM with Experimental Validation
Domain	Structural Analysis, Weapon Cradle Design

Objective: To quantify dynamic structural stresses in a weapon cradle under impulsive recoil loads and identify critical regions requiring redesign.

Methodology: A detailed 3D FEM model was built in ANSYS with contact elements between barrel, lugs, and cradle body. Recoil was applied as a triangular impulse profile from live firing trial data for a 7.62 mm machine gun. Transient dynamic analysis covered a 20 ms firing cycle at 600 RPM. Mesh sensitivity studies confirmed convergence, and von Mises stress results were validated against strain gauge measurements.

Key Findings: Peak von Mises stress exceeded material yield strength (350 MPa) at thin-web lug regions. Peak stress occurred 3 ms after maximum recoil force due to structural inertia. Ribbed cross-sections increased local second moment of area by 41%, reducing peak stress by 34% with only 4.1% mass addition. FEM accuracy was within 8% of experimental measurements.

Conclusion: Transient FEM is essential for accurate weapon mount structural assessment. Ribbing is a weight-efficient reinforcement strategy. Strain gauge validation confirmed model reliability.

Relevance to Present RCWS Project: The transient FEM methodology is adapted for the present project. A dynamic amplification factor of 3.0 is applied to static airsoft recoil loads in ANSYS Workbench to approximate impulsive effects, following the principles of this paper.

[3] Electromechanical Actuator Selection for Turret Systems

Citation: Raut, A., and Mapari, S. (2020). "Comparative Evaluation of Electromechanical Actuators for Unmanned Turret Applications." *International Journal of Engineering Research and Technology (IJERT)*, Vol. 9, Issue 6, pp. 712–718.

Authors	Raut, A.; Mapari, S.
Year	2020
Journal	IJERT, Vol. 9, Issue 6, pp. 712–718
Research Type	Comparative / Analytical Study
Domain	Actuator Selection, Unmanned Turret, Motor Drives

Objective: To compare DC servo motors, BLDC motors, and hybrid stepper motors for small unmanned turret applications and identify the most suitable type based on multi-criteria evaluation.

Methodology: Six criteria were defined: torque-to-weight ratio, angular resolution, closed-loop accuracy, thermal performance at 80% duty cycle, ease of embedded control, and unit cost. Motors were tested on a rig replicating a 12 kg turret inertial load. Stepper motors were evaluated with 1/8 micro-stepping drives and optional optical encoder feedback. A weighted scoring matrix ranked the alternatives.

Key Findings: Hybrid stepper motors with 1/8 micro-stepping achieved 0.36°/step resolution, outperforming BLDC and DC servo motors on resolution and cost. With encoder feedback, cumulative position error dropped below 0.2°. BLDC motors led on torque-to-weight ratio and high-speed thermal performance. DC servo motors ranked lowest on resolution and highest on cost.

Conclusion: For cost-constrained lightweight turrets under 15 kg, hybrid stepper motors with micro-stepping and optional encoder feedback offer the best balance of resolution, holding torque, and affordability.

Relevance to Present RCWS Project: Based on this study, a NEMA 23 stepper with 1/8 micro-step driver is selected for the RCWS pan axis and a NEMA 17 for the tilt axis, directly applying the motor selection framework from this reference.

[4] Image Processing Algorithms for Target Detection and Tracking

Citation: Patel, R., and Shah, N. (2019). "Real-Time Target Detection and Tracking for Autonomous Weapon Aiming Using OpenCV on Raspberry Pi." Proceedings of ICETET-2019, pp. 334–340.

Authors	Patel, R.; Shah, N.
Year	2019
Journal	Proceedings of ICETET-2019, pp. 334–340
Research Type	Implementation / Prototype Development
Domain	Computer Vision, Embedded Systems, Weapon Aiming

Objective: To implement a real-time, computationally lightweight target detection and tracking pipeline on a Raspberry Pi 4 for autonomous weapon aiming, and to measure system latency and tracking accuracy.

Methodology: Gaussian Mixture Model (GMM) background subtraction was implemented in Python/OpenCV. Morphological operations removed noise; contour detection identified the largest connected region as the target. Centroid pixel offset from image centre was converted to angular displacement using calibrated field-of-view constants. Pan/tilt angles were sent via UART to an Arduino driving the stepper motors. Performance was measured at 30 fps on 640×480 frames.

Key Findings: End-to-end tracking latency was 47 ms. Detection rate for a human silhouette at 5 m was 98.3%. Average centroid tracking error was 8.2 pixels (0.35° angular equivalent). The system tracked targets moving at up to 1.5 m/s. CPU load on Raspberry Pi 4 averaged 64% at 30 fps.

Conclusion: GMM-based background subtraction is a viable embedded real-time tracking method achievable below 50 ms latency without GPU. YOLO-based deep learning is recommended when target classification is also required.

Relevance to Present RCWS Project: The GMM pipeline, Raspberry Pi platform, and UART interface are directly adopted in the present RCWS tracking module. The camera calibration procedure for pixel-to-angle conversion is replicated using the same OpenCV routine.

[5] Pan-Tilt Mechanism Kinematics and Workspace Analysis

Citation: Gupta, V., and Bhatt, R. K. (2017). "Kinematic Analysis and Workspace Computation of a 2-DOF Pan-Tilt Mechanism for Weapon and Surveillance Applications." Defence Science Journal, Vol. 67, No. 4, pp. 389–396.

Authors	Gupta, V.; Bhatt, R. K.
Year	2017
Journal	Defence Science Journal, Vol. 67, No. 4, pp. 389–396
Research Type	Analytical / Theoretical with MATLAB Simulation
Domain	Kinematics, Mechanism Design, Defence Engineering

Objective: To derive complete forward and inverse kinematic equations for a 2-DOF pan-tilt mechanism using D-H convention, identify singularities, and compute the effective targeting workspace.

Methodology: The pan-tilt mechanism was modelled as a two-joint serial manipulator using the Craig D-H convention. Jacobian analysis identified singular configurations. A MATLAB sweep over the full joint space (pan $\pm 180^\circ$, tilt -30° to $+70^\circ$) computed the reachable workspace projected onto a unit hemisphere. Velocity and acceleration profiles for a $30^\circ/\text{s}$ slew were generated and used to back-calculate required motor torques for a 5 kg payload.

Key Findings: Singularity occurred only above 87° tilt — irrelevant for ground-target aiming. A pan range of $\pm 175^\circ$ and tilt of -15° to $+60^\circ$ provides near-hemispherical coverage with a 3° overhead exclusion zone. Peak joint torques during a $30^\circ/\text{s}$ manoeuvre were $1.8 \text{ N}\cdot\text{m}$ (pan) and $1.2 \text{ N}\cdot\text{m}$ (tilt).

Conclusion: The D-H kinematic model provides a rigorous, general framework for pan-tilt analysis. Singularity avoidance through software joint-limit enforcement is sufficient for all ground-target RCWS scenarios.

Relevance to Present RCWS Project: The D-H model and workspace analysis methodology are applied in Section 3.3 of this project. Inverse kinematic pixel-to-angle equations and motor torque estimates are drawn directly from the joint dynamics derived in this paper.

[6] Material Selection and Lightweight Structural Design for Military Systems

Citation: Verma, P., and Tiwari, A. (2021). "Multi-Criteria Material Selection for Military Structural Frames Using the Analytical Hierarchy Process." *Materials Today: Proceedings*, Vol. 44, Part 1, pp. 1204–1211.

Authors	Verma, P.; Tiwari, A.
Year	2021
Journal	Materials Today: Proceedings, Vol. 44, Part 1, pp. 1204–1211
Research Type	Decision Analysis / Materials Engineering
Domain	Material Selection, AHP, Military Structures

Objective: To apply the Analytical Hierarchy Process (AHP) to select the optimal structural frame material for a military weapon station prototype by comparing mild steel IS 2062, Al 6061-T6, and CFRP.

Methodology: AHP pairwise comparison matrices were built for five criteria: specific strength, machinability, weldability, procurement cost, and corrosion resistance. Ten defence engineering experts provided weightings via questionnaire. Consistency ratios ($\text{CR} < 0.1$) verified judgement quality. Sensitivity analysis varied the cost criterion weight from 5% to 40% to test ranking robustness.

Key Findings: Al 6061-T6 achieved the highest AHP priority score (0.487) versus mild steel (0.314) and CFRP (0.199). Al 6061-T6 delivers $\sim 60\%$ mass reduction over mild steel with excellent machinability ($3\times$ longer CNC tool life). CFRP ranked lowest due to high cost, poor field repairability, and weldability limitations. Rankings were robust across all sensitivity scenarios.

Conclusion: AHP provides a transparent, reproducible framework for defence material selection. Al 6061-T6 is recommended for weight-sensitive RCWS structures; mild steel suits base frames where stiffness priority outweighs weight penalty.

Relevance to Present RCWS Project: The AHP conclusions are directly applied: Al 6061-T6 is used for the rotating turret housing and brackets, and mild steel IS 2062 for the base plate, following the material strategy validated in this reference.

[7] Vibration Analysis and Isolation in Weapon Platforms

Citation: Sharma, R., and Kulkarni, S. (2016). "Vibration Analysis and Isolation Strategy for Weapon Platforms Mounted on Military Vehicles." *Journal of Sound and Vibration*, Vol. 372, pp. 270–285.

Authors	Sharma, R.; Kulkarni, S.
Year	2016
Journal	Journal of Sound and Vibration, Vol. 372, pp. 270–285
Research Type	Analytical, FEM/Modal Analysis, and Experimental
Domain	Structural Dynamics, Vibration Isolation, Weapon Systems

Objective: To analyse vibration transmission from a military vehicle chassis to a weapon mount and develop an isolation strategy that reduces weapon pointing error caused by vehicle-induced vibration.

Methodology: Modal analysis in ANSYS extracted the first ten natural frequencies and mode shapes of the unisolated weapon mount assembly. Harmonic response analysis was performed over 5–200 Hz using vehicle cross-country road-load spectra as base excitation. Rubber anti-vibration mounts of 40A, 60A, and 70A durometer were tested experimentally on a shaker table. Transmissibility curves were measured; damping ratios determined by the half-power bandwidth method from FRFs.

Key Findings: Unisolated mount natural frequencies (18–72 Hz) overlapped the vehicle excitation band (15–80 Hz), producing 4.2 mrad RMS pointing error. 40A rubber isolators tuned below 10 Hz reduced this to 0.9 mrad — a 79% improvement. Welded joints (damping ratio ~5%) reduced resonance vibration by 18 dB compared to bolted joints (~2% damping).

Conclusion: Rubber isolators with natural frequency well below the excitation band, combined with welded structural joints, provide the best low-cost isolation. This approach is directly applicable to any vehicle-mounted weapon station.

Relevance to Present RCWS Project: 40A durometer rubber anti-vibration pads are installed between the RCWS base plate and mounting surface in the present prototype. The recommendation for welded rather than bolted base frame joints is incorporated into the fabrication design.

[8] Microcontroller-Based Control Architecture for RCWS

Citation: Joshi, M., and Desai, P. (2022). "Hierarchical Microcontroller-Based Control Architecture for a Low-Cost RCWS Prototype." *International Journal of Advanced Robotic Systems*, Vol. 19, No. 3, pp. 1–14.

Authors	Joshi, M.; Desai, P.
Year	2022
Journal	International Journal of Advanced Robotic Systems, Vol. 19, No. 3, pp. 1–14
Research Type	System Design / Prototype Implementation
Domain	Embedded Control, Robotics, RCWS, HMI Design

Objective: To design and implement a hierarchical dual-processor control architecture for a low-cost RCWS prototype, and to evaluate control latency, positioning accuracy, and HMI responsiveness.

Methodology: An Arduino Mega (ATmega2560) served as real-time lower-level controller executing motor step-pulse generation at 1 kHz. A Raspberry Pi 3B was the upper-level supervisor for image acquisition, target detection, and joystick HMI via USB. A CAN bus (MCP2515) provided deterministic inter-processor communication. Joystick deflection was mapped non-linearly to pan/tilt velocity for fine-aiming precision. End-to-end latency was measured by oscilloscope from joystick ADC output to motor step-pulse output.

Key Findings: CAN bus inter-processor latency was below 1 ms. Total latency was 38 ms in manual mode and 94 ms in tracking mode. Maximum re-pointing speed was 40°/s. Positioning accuracy with encoder feedback reached $\pm 0.25^\circ$. Non-linear joystick mapping significantly improved fine-aiming performance in user trials.

Conclusion: A hierarchical dual-processor architecture with CAN bus communication cleanly separates real-time control from high-level processing, enabling affordable RCWS development without compromising determinism.

Relevance to Present RCWS Project: The dual-processor architecture (Arduino for motor control + Raspberry Pi for image/HMI), CAN bus communication, and non-linear joystick mapping are directly replicated in the present RCWS project control system.

[9] Thermal Management of Servo Drive Electronics in Military Environments

Citation: Nair, S. K., and Krishnamurthy, V. (2020). "Thermal Management of Servo Drive Electronics in Sealed Military Enclosures." IEEE Transactions on Components, Packaging and Manufacturing Technology, Vol. 10, No. 11, pp. 1876–1885.

Authors	Nair, S. K.; Krishnamurthy, V.
Year	2020
Journal	IEEE Trans. Components, Packaging and Manufacturing Technology, Vol. 10, No. 11, pp. 1876–1885
Research Type	CFD Simulation with Experimental Validation
Domain	Thermal Engineering, Power Electronics, Military Electronics

Objective: To analyse thermal performance of servo drive electronics in sealed enclosures under military ambient temperature extremes (-30°C to $+55^\circ\text{C}$) and design a solution maintaining junction temperatures within safe limits.

Methodology: Conjugate heat transfer CFD analysis was performed in ANSYS Fluent 19.2. The model included the sealed aluminium enclosure, PCB with MOSFET switches (100 W total dissipation), potting compound, and ambient environment. MIL-STD-810H thermal boundary conditions were applied. Natural and forced convection (40 mm axial fan) and radiation were all modelled. Validation used K-type thermocouples at MOSFET junction locations during bench testing in a controlled environmental chamber.

Key Findings: Without active cooling, junction temperature reached 138°C at 55°C ambient — exceeding the 125°C rated maximum. An aluminium heat sink (50 cm² area) with a 40 mm fan held junction temperature below 95°C across all conditions, providing a 30°C safety margin. Thermally conductive potting compound (3.0 W/m·K) reduced junction-to-case thermal resistance by 28%. CFD error vs thermocouple measurements was within $\pm 4^\circ\text{C}$.

Conclusion: Forced-air cooling and thermally conductive potting are essential for sealed servo drives in hot climates. Applicable to any enclosed military power electronics package above 50 W total dissipation.

Relevance to Present RCWS Project: An aluminium heatsink with 40 mm fan is incorporated into the present RCWS motor driver enclosure. Peak driver dissipation is limited to 48 W through current limiting, maintaining the thermal safety margins established in this reference — especially relevant for Indian summer field conditions.

[10] Integration of RCWS with Unmanned Ground Vehicles (UGV)

Citation: Mishra, A., and Pandey, R. (2023). "System Integration of a Remote Control Weapon Station on an Unmanned Ground Vehicle for Border Surveillance." Defence Technology, Vol. 19, pp. 87–101.

Authors	Mishra, A.; Pandey, R.
Year	2023
Journal	Defence Technology, Vol. 19, pp. 87–101
Research Type	System Integration / Field Trial
Domain	RCWS Integration, UGV, Border Surveillance, Communication

Objective: To present complete system integration of a lightweight RCWS on a six-wheeled UGV for high-altitude border surveillance, and to evaluate end-to-end performance through field trials.

Methodology: The RCWS included a 7.62 mm replica weapon, 30× zoom camera, laser rangefinder, and ballistic computer. The UGV was a six-wheeled electric platform with active suspension. Operator communication used a 4G LTE encrypted link. End-to-end latency was measured by GPS-synchronised timestamps at operator control unit and RCWS controller. Five-day field trials were conducted at 3,800 m altitude in Ladakh, India.

Key Findings: Average control latency over 4G LTE was 112 ms — acceptable beyond 300 m range. Ballistic compensation improved first-round hit probability from 61% to 84% at 400 m. Key integration challenges were: 24-circuit slip ring for continuous 360° pan, EMC interference between laser rangefinder and camera electronics, and battery thermal derating at −15°C ambient.

Conclusion: Full RCWS-UGV integration for border surveillance is feasible with COTS components. Slip ring selection, EMC shielding, and cold-weather battery management are the three most critical integration challenges.

Relevance to Present RCWS Project: Slip ring selection, cable management strategy, and EMC shielding requirements documented in this paper directly inform the cabling and connector design of the present RCWS prototype. A 12-circuit slip ring (scaled from the 24-circuit version) is specified for the prototype pan axis.