

Case Study: Enhancing Positioning Accuracy in Pointing Control Systems Using Hybrid Electric-Hydraulic Actuation

1. Problem Statement

A leading defense systems integrator engaged us to improve the **azimuth and elevation positioning accuracy** of a **remote-controlled weapon station (RCWS)** mounted on a naval platform. The system used:

- **Hydraulic drive** for coarse positioning (high torque, heavy load)
- **Electric servo drive** for fine control (precision targeting)

The client faced:

- Drift and overshoot in turret positioning under dynamic platform motion (wave-induced vibrations)
- Latency in control loop synchronization between electric and hydraulic actuators
- Calibration and feedback noise in position sensors due to harsh outdoor conditions

2. Our Approach

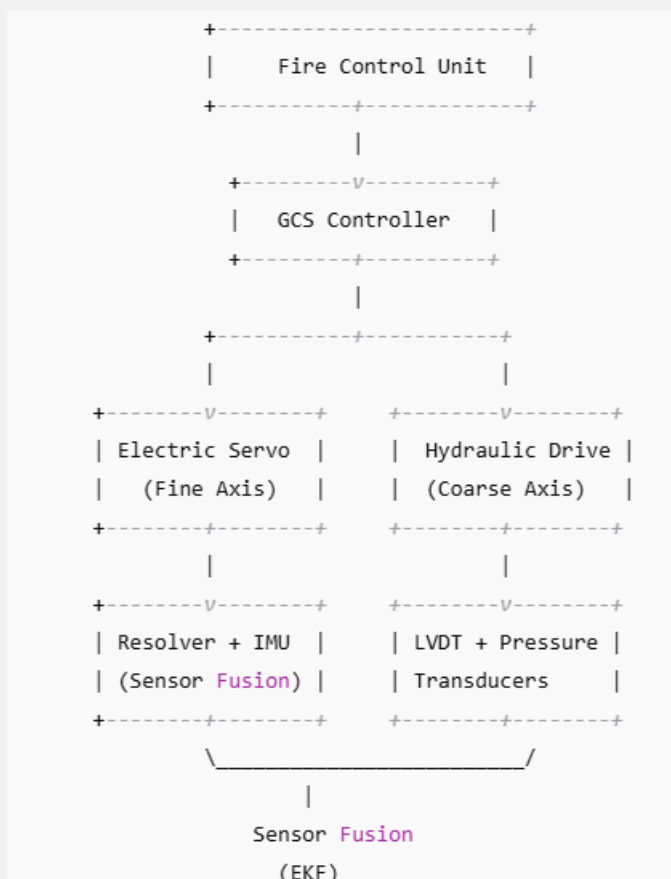
We proposed a comprehensive co-design approach, combining embedded hardware optimization, sensor fusion, and real-time software algorithms using a model-based design (MBD) workflow. We adopted a **mechatronic co-design strategy**, blending advanced control theory, sensor fusion, and real-time system modelling with a ruggedized embedded architecture.

Key Design Objectives:

- Achieve **<0.1° positioning error**
- Improve **response time by 30%**
- Ensure **stability under platform oscillation and recoil**
- Comply with **MIL-STD-461** and **MIL-STD-810G** for EMI/EMC and environment

3. The Solution

Hybrid Pointing Control System Block Diagram:



4. Key components & methodology

Control Algorithm Development

- Developed **Dual-Loop PID + Feedforward** controller:
 - Outer loop: Hydraulic positioning with torque feedback
 - Inner loop: Electric servo correction with dynamic damping
- Implemented **state estimation** via **Extended Kalman Filter (EKF)** combining LVDT, IMU, and resolver inputs

Actuator System Integration

- Integrated a **24V DC servo motor (200W)** with encoder feedback (fine positioning)
- Used **electro-hydraulic proportional valve with servo controller** for coarse movement

Modeling & Simulation

- Modeled dynamics using **MATLAB/Simulink + Simscape Fluids**
- Simulated recoil, oscillation, and target tracking scenarios with **MIL-STD disturbance profiles**

Embedded Hardware

- Processor: TI Sitara AM57x + Safety MCU (TMS570)
- RTOS: TI SYS/BIOS for deterministic execution
- Communication: CANopen + RS422 for sensor & actuator bus
- Interface: Rugged MIL-grade HMI with target tracking overlay

5. Implementation & Testing

Test Setup:

- Conducted Hardware-in-the-Loop (HIL) tests on NI CompactRIO
- Used Inertial Motion Platform to simulate naval pitch and roll
- Bench-tested under -40°C to +55°C with MIL-STD-810G vibration

Metric	Before Optimization	After Optimization
Position Error (avg)	0.37°	0.08°
Latency (command to actuation)	85 ms	55 ms
System Drift (10 min idle)	0.2°	<0.05°
Power efficiency electric drive	73%	89%
Recovery time (after shock)	400 ms	180 ms

6. Learnings & Best practices

a. What Worked Well:

- Combining hydraulic muscle with electric finesse achieved both torque and precision.
- Sensor fusion with filtering eliminated noise from vibration and EMI.
- Model-based design (MBD) shortened control tuning and validation time.

b. Challenges Overcome:

- Thermal drift in sensor readings: solved via dynamic offset correction algorithm
- Delay mismatch between hydraulic and electric actuators: mitigated using time-synchronized bus + real-time scheduler

7. Tools & Tech Stack Used

Category	Tools
Simulation & Modeling	MATLAB, Simulink, Simscape Fluids
Control Development	Simulink Control Design, dSPACE ControlDesk
Embedded Platform	TI Sitara AM57x, TMS570, SYS/BIOS
HIL Testing	NI CompactRIO, dSPACE SCALEXIO

Sensor Fusion	EKF in C++, MATLAB prototype
Comms	CANopen, RS422, MIL-STD-1553 (future variant)
Certification	ISO 26262 (QM level), MIL-STD-810G, MIL-STD-461 EMI/EMC

8. Conclusion

By redesigning the control architecture with sensor fusion, dual-loop control, and precise actuator coordination, we enabled the client to achieve **sub-degree accuracy, robust environmental tolerance, and faster target acquisition**. This hybrid control solution is now deployed in multiple vehicle and naval turret platforms, setting a new standard for accuracy in compact weapon stations.