Low-Power Magnetic Linear Actuator for Camera Positioning

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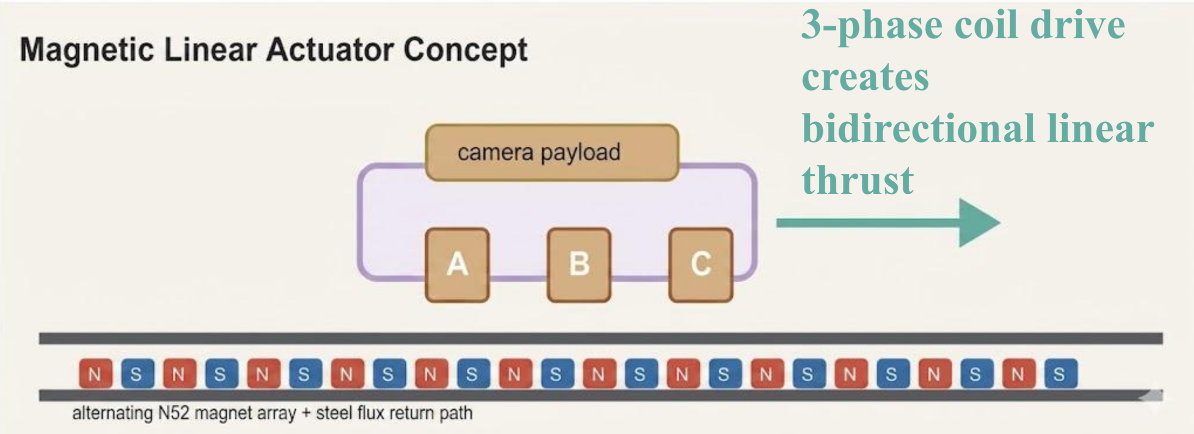
I - Motivation & Requirements

- **Motivation:** In space observation, fixed cameras limit the accurate measurement of astronomical events across a wide sky. A linearly actuating camera-cart system is proposed to track movement and solve this limitation.
- **Power Requirement:** The magnetic actuator must operate at < 1 A to enable continuous camera repositioning throughout an overnight session.
- **Control Requirement:** Wireless control.

Runtime ≥12 [hr]	Travel 300 [mm]	Accuracy ±1 [mm]	Wireless Control

II - Selected System Concept

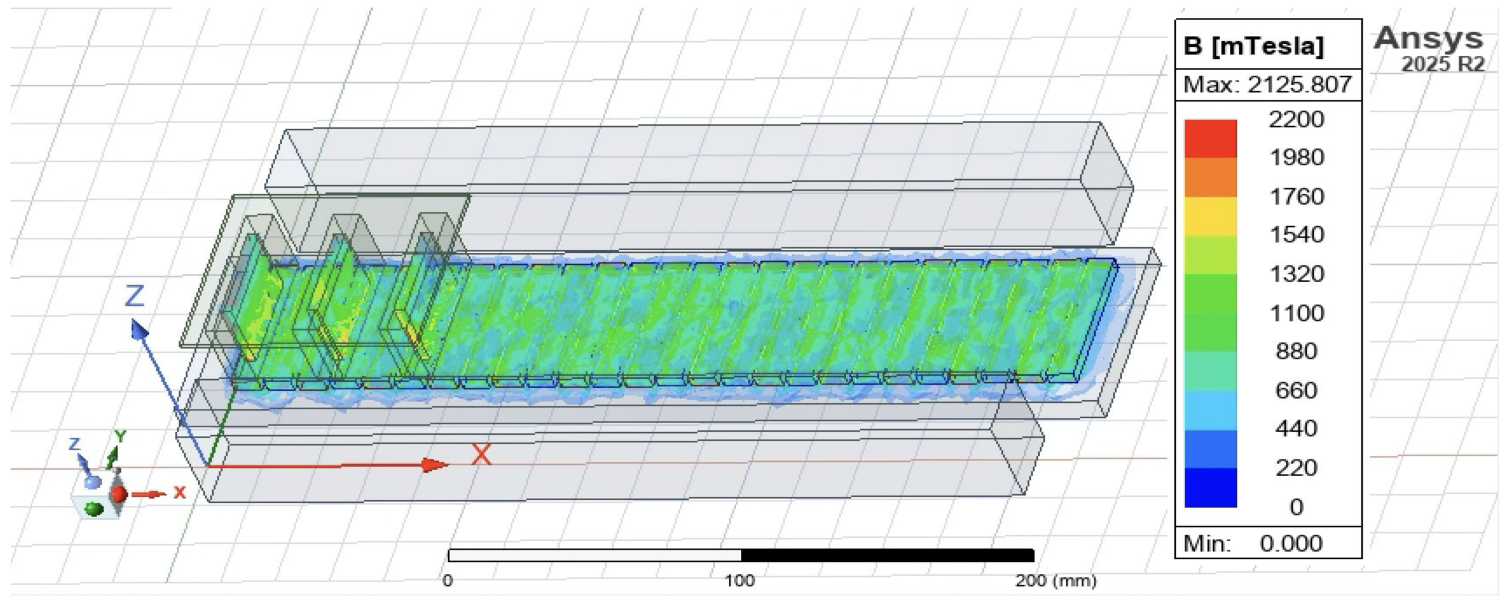
Three coils attached to an E-shaped core ride above an alternating-polarity magnet array. A steel back plate concentrates flux through an air gap. 3-phase block commutation produces Lorentz-force thrust so that no lead screw, no belt, nor traditional motor is used.



III - Magnetic Design Targets

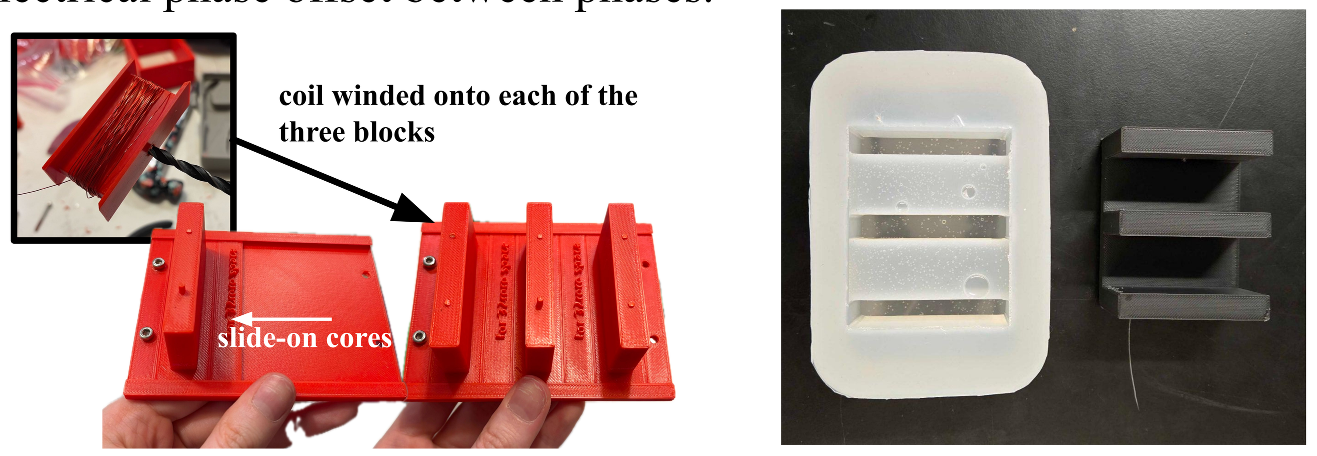
Magnetic Force design eq: $F = K_f \cdot I \qquad K_f = B \cdot L_{total}$

- Magnet force Br = 1.42–1.48 [T] · 23 alternating 60×10×3/5 [mm] blocks
- Air gap: 1.5 [mm]
- Coil Resistance: ≈52 [Ω]
- Kf (force constant) tolerance: ±8–10% from air-gap and fabrication stack-up
- Analytical target: Kf = 15–18 [N/A] · Bgap = 0.90–1.05 [T]

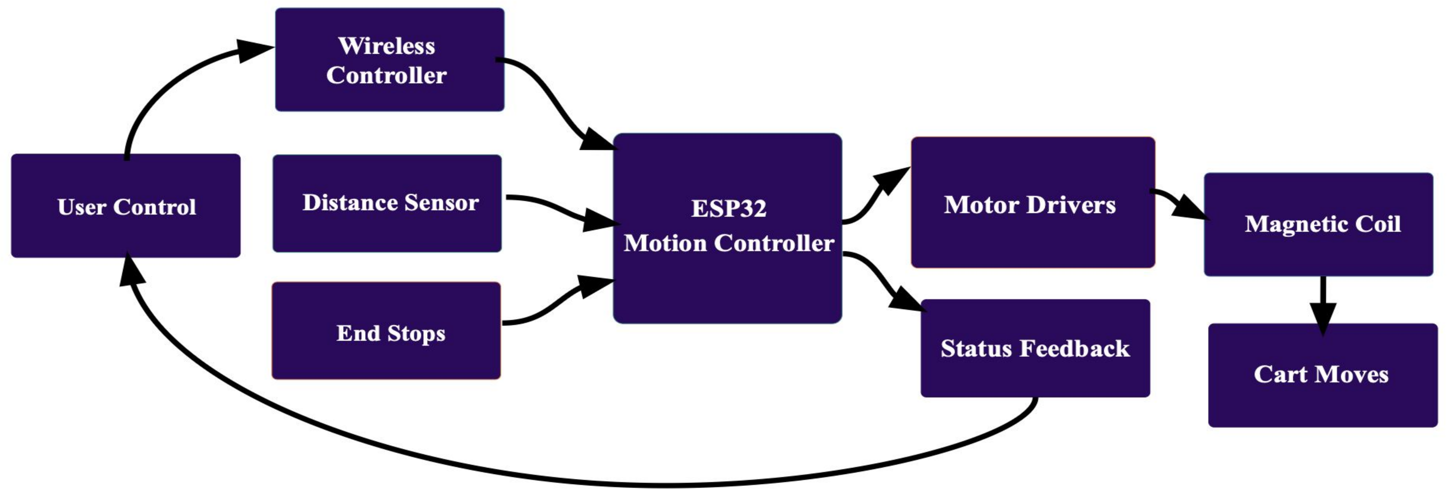


IV - Prototype & Final Core Architecture

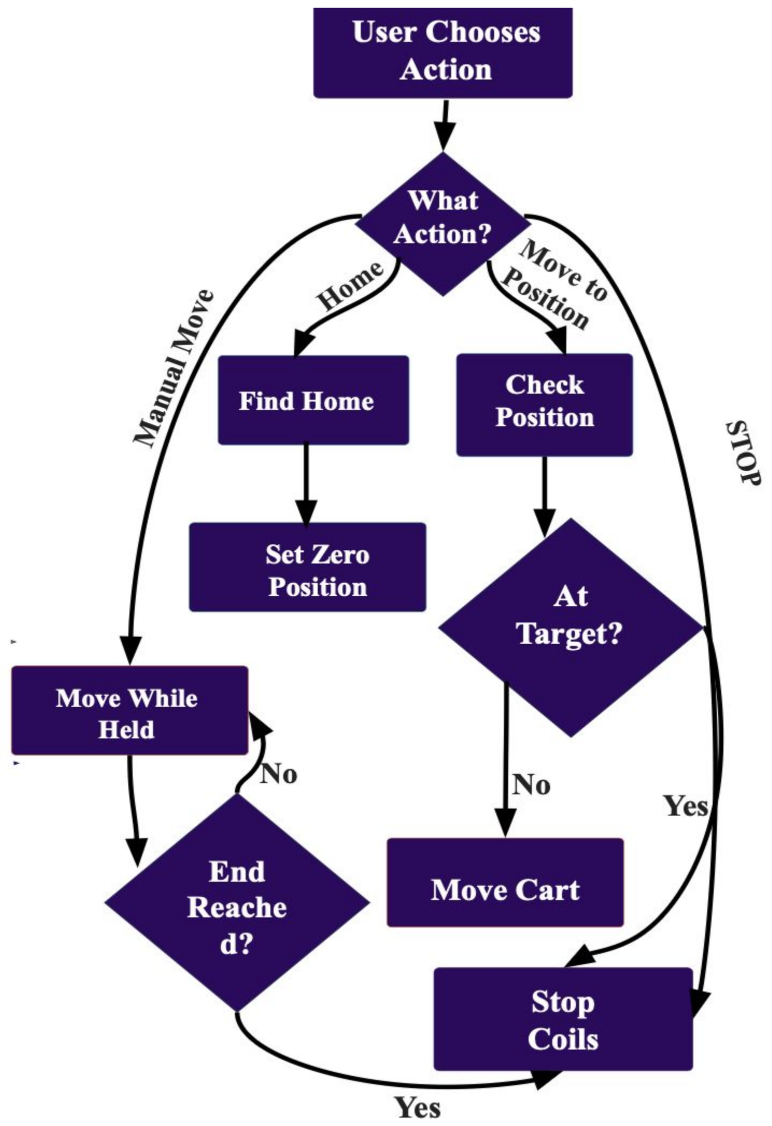
3D-printed modular cores allow rapid coil-winding in prototype testing. In the final iteration, an epoxy and iron mixed E-core was made using a silicone mold casting, with pre-winded coils that slide onto each leg. All coils are spaced 32 mm center-to-center, matching magnet pitch for 120° electrical phase offset between phases.



V - Software Control Architecture

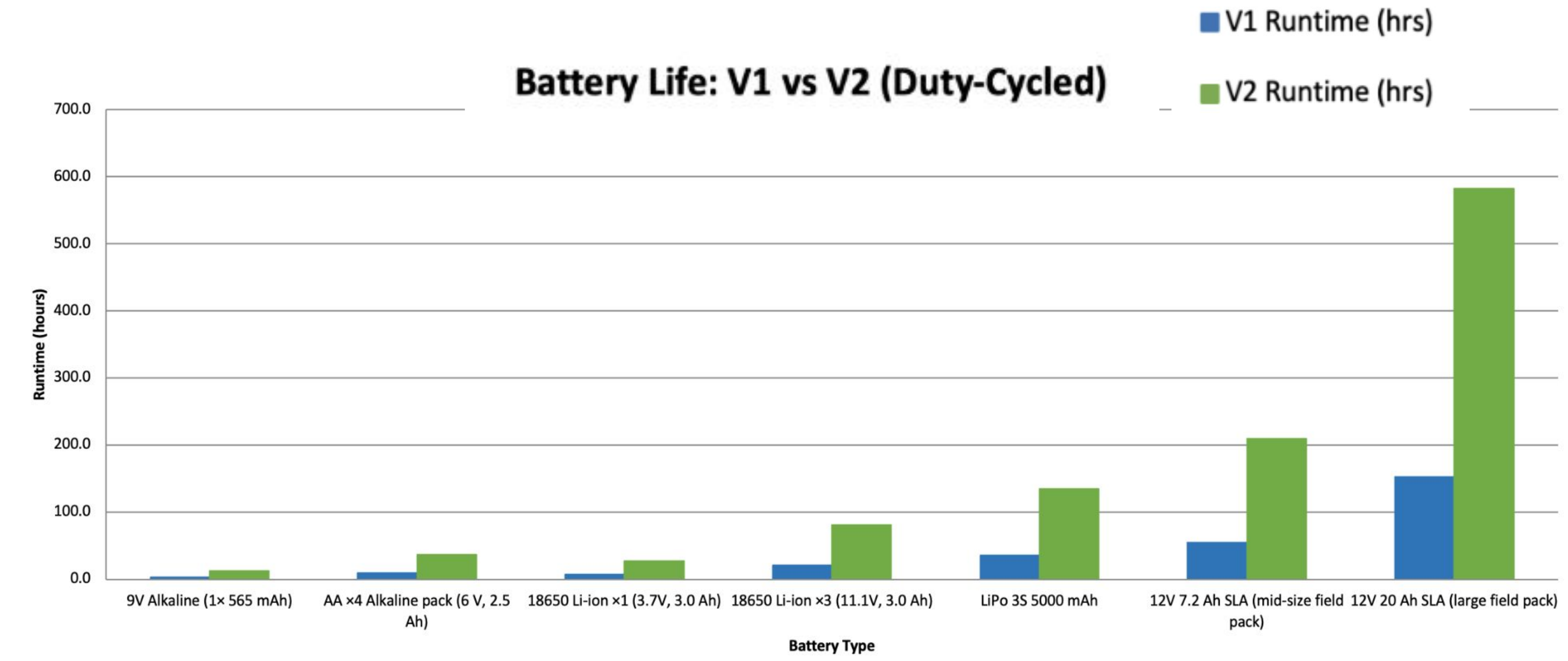


- Top flowchart shows overall system logic, while the bottom flowchart shows user command flow.
- **Hardware Architecture:** ESP32 integrates wireless telemetry and sensor feedback for closed-loop control.
- **Motion State Machine:** Automated decision logic governs safe positioning and precise coil commutation.



VI - Simulations & Results

- **Simulated Battery Life: 135 hours (at 10% duty cycle)** using a 5000 mAh 3S LiPo.
- **FEA Insight:** Simulation (Kf = 2.21 [N/A]) identified coil redesign as the critical path to further optimize low-current operation.



VII - FINAL RESULTS

The system achieves low-current operation with an active draw of **0.446 [A]** and **idle draw of 0.03 [A]**, well below the 1 [A] target. Other functional requirement results below.

12+ [hr] operation on 3S 5200 [mAh] LiPo	Travel 280 [mm]	2.33 [mm] RMS error	Successful wireless control

VIII - FUTURE WORK / CONCLUSION

- **Conclusion:** Validated low-current, wireless bidirectional control for space observation.
- **Coil Redesign:** Optimize geometry to increase active wire length for higher thrust at lower currents.
- **Precision:** Upgrade control algorithms to achieve the ≤1 mm accuracy target.
- **Power Management:** Disable ToF sensor during idle states to further maximize battery life.

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