

Bill of Materials: Pivot Motion Tracker (PMT)

Role: Kinematic & Hydraulic Auditor | Ratio: 1 per Pivot | Reporting To: VFA (Field Aggregator)

The PMT serves as the high-fidelity "Nervous System" of the center-pivot machine. It tracks exactly where the pivot is in its 360-degree rotation (spatial positioning) and precisely how much water is moving through the main span (hydraulic flow). This data is the empirical backbone of the "Digital Ledger," allowing the Zo engine to correlate soil moisture pings from the LRZ scouts with actual irrigation application events in real-time.

1. Structural Housing & Mounting

The PMT is an above-ground asset, meaning it faces the most brutal environmental stressors in the San Luis Valley—intense UV, 100mph wind gusts, and "sand-blasting" from alkali dust.

- **Enclosure:** NEMA 4X UV-Stabilized Polycarbonate Box (8"x6"x4").
 - *Material Logic:* Polycarbonate is utilized for its impact resistance and RF-transparency. Unlike steel boxes, it allows the internal GNSS and BLE antennas to maintain high-gain locks without the need for externalized "puck" antennas that are prone to being sheared off by low-hanging branches or pivot hardware.
 - *Mounting:* Heavy-duty 304 Stainless Steel "Band-It" straps. These provide a high-torque, non-destructive attachment to the main 6.625" or 8.625" pivot span. The stainless steel construction is mandatory to prevent galvanic corrosion between the mounting hardware and the galvanized pivot pipe.
- **Environment:** Rated for -40°F to 140°F.
 - *Atmospheric Engineering:* Includes a dual-stage Gore-Tex vent. This is critical for pressure equalization; during the rapid temperature drops common in Colorado alpine basins (e.g., a 40°F drop in 30 minutes), the vent allows the enclosure to "breathe" without sucking in moisture-laden air that would otherwise condense on the electronics and cause catastrophic short-circuiting.

2. Kinematic & Positioning Stack

The PMT must differentiate between "Walking" (pivot in motion) and "Pumping" (water moving) to provide a 1m-accurate audit.

- **GNSS Engine:** High-Precision Multi-Constellation Module (GPS, GLONASS, Galileo) with Internal Active Patch Antenna.
 - *Spatial Logic:* By tracking multiple constellations, the PMT maintains a sub-2.5m horizontal accuracy even during heavy cloud cover or "thermal shimmer." This allows

Zo to map irrigation "slices" to specific 1m grid tiles, identifying exactly which hectares received water and which were missed due to nozzle clogs.

- **9-Axis IMU (Inertial Measurement Unit):** Bosch BNO055 or equivalent.
 - *The "Crabbing" Detector:* Beyond simple motion, the IMU measures the "Tilt" and "Vibration" of the first tower. It can detect "crabbing"—where a tower's drive motor is slipping, causing alignment drift.
 - *Implication:* By detecting mechanical stress before a structural failure occurs (e.g., a "bowing" span), the PMT acts as a preventative maintenance tool, potentially saving the farmer \$100k+ in catastrophic pivot collapse repairs.

3. Hydraulic Audit Stack (The Flow Meter)

- **Ultrasonic Transducers:** Transit-Time Clamp-on Transducers (Non-Invasive).
 - *Physical Logic:* These transducers utilize a "V-Mount" or "Z-Mount" configuration on the exterior of the pipe. They send ultrasonic pulses through the water; the difference in "transit-time" between upstream and downstream pulses is directly proportional to the water's flow velocity.
 - *Non-Invasive Advantage:* Because these sensors clamp to the outside of the 6", 8", or 10" main pipe, they require zero "cutting or welding." This preserves the structural integrity of the pivot and ensures there is zero pressure drop, which would otherwise increase the energy cost of pumping.
 - *Accuracy:* $\pm 1.0\%$ of flow rate—exceeding the State Water Court "Digital Ledger" requirements for certified water use reporting.

4. Internal Electronics & Communication

- **Core MCU:** Nordic nRF52840 (Shared Architecture with VFA).
 - *Edge Processing:* The MCU buffers 1-second interval flow data and GNSS coordinates. It applies a Kalman Filter to the IMU data to smooth out the vibration noise of the pivot's drive motors, then transmits a condensed "Audit Packet" to the VFA every 60 seconds.
- **Expanded Power Stack:** Dual-Pack LiFePO4 (40,000mAh total).
 - *Thermal Management:* Integrated 5W Kapton heater + 8mm PE Closed-Cell Foam insulation. Unlike buried sensors, the PMT is exposed to ambient "Wind Chill" effects. The heater is programmed to engage at 35°F to ensure the battery chemistry stays within the safe charging window, drawing power from the VFA's solar distribution line or its own integrated 20W solar lid.
- **Comms:** High-Gain BLE 5.0 (Long Range Mode).

- *The RF Barrier:* Specifically tuned to penetrate the "RF screen" created by the pivot's massive steel structure and the curtain of falling water. By using coded PHY (Long Range), the PMT maintains a reliable handshake with the VFA mast even at the furthest point of the pivot's swing.

Funding & Compliance Note: The PMT is the "Gold Standard" for verified water use. It is 100% eligible for subsidization via State (CWCB) and Federal (NRCS) water conservation grants. By providing an automated, tamper-proof "Digital Ledger" of every gallon pumped, it reduces the farmer's administrative burden for State Engineer reporting while securing their long-term water rights through empirical proof of beneficial use.