Master Specification: Pivot Motion Tracker (PMT) V1.6

Role: Kinematic & Hydraulic Auditor | **Network Density:** 1 per Pivot (Subdistrict 1 Deployment)

The Pivot Motion Tracker (PMT) serves as the high-fidelity "Nervous System" and the primary "Hydraulic Auditor" of the FarmSense SFD (Single Field Deployment) architecture. Positioned externally on the main span of a center-pivot irrigation machine, it provides the essential kinematic and hydraulic flow data required to verify exactly where, when, and how much water is applied to the land. While the LRZ (Lateral Root-Zone) scouts monitor the soil's *response* to water, the PMT provides the certified *proof of application*, completing the data loop for the Zo Scientist Engine and establishing the legal foundation for the "Digital Water Ledger."

Subdistrict 1 Economics & Strategic Procurement: This version of the specification reflects the optimized procurement strategy for the **1,280-unit deployment in Subdistrict 1**. At this scale, FarmSense leverages high-volume industrial discounts from established, reliable suppliers (such as Polycase, SparkFun, and Badger Meter) rather than attempting full custom silicon integration at this stage. This ensures immediate field reliability, insurance-backed liability protection, and professional-grade accuracy for Water Court auditing.

1. Structural Housing & "Cut-Less" Mounting Logistics

Because the PMT is an above-ground asset mounted directly to massive moving steel machinery, it faces extreme environmental stressors: intense high-altitude UV, 100mph alpine wind gusts, and continuous sand-blasting from alkali dust.

- **The Enclosure (RF-Transparent Architecture):** Housed in an **IP67 UV-Stabilized Polycarbonate Box (8"x6"x4")** from Polycase.
    - *Material Logic:* Polycarbonate provides superior impact resistance, ensuring the unit survives accidental strikes from low-hanging branches or pivot hardware. It is also inherently RF-transparent, allowing the internal high-precision GNSS and BLE antennas to maintain high-gain locks without the need for fragile externalized "puck" antennas that are prone to being sheared off during operation.
    - *Environmental Defense:* The enclosure features a dual-stage Gore-Tex breather vent. During rapid alpine temperature drops (e.g., a 40°F drop during a sudden storm), this prevents the box from creating an internal vacuum that would suck in moisture-laden outside air through the gaskets, causing catastrophic condensation on the logic boards.
- **"Cut-Less" Mounting (Zero-Impact Integration):** Attached to the main galvanized pivot span (typically 6.625" or 8.625" OD) using heavy-duty **304 Stainless Steel "Band-It"**

straps combined with a **Neoprene Friction Pad**.

- *Structural Integrity:* This non-invasive mount requires zero drilling, welding, or tapping into the pivot's span, preserving the manufacturer's structural warranty and preventing point-source corrosion. The Neoprene pad acts as a critical vibration dampener, isolating the sensitive IMU and GNSS electronics from the rhythmic mechanical "clanking" of the pivot's electric drive motors and gearboxes.

2. Kinematic Positioning & Structural Audit Stack

The PMT moves beyond simple GPS tracking to professional-grade kinematic auditing, differentiating mathematically between "Walking" (motion without water) and "Pumping."

- **High-Precision GNSS Engine (RTK-Ready):** Utilizes a **u-blox ZED-F9P RTK GNSS** module sourced via SparkFun.
  - *Spatial Precision:* By simultaneously tracking multiple satellite constellations (GPS, GLONASS, Galileo, BeiDou), the PMT maintains sub-2.5m horizontal accuracy even during heavy cloud cover or atmospheric thermal shimmer.
  - *The 1m "Resolution Pop":* This precision data is the empirical backbone of the FarmSense UI. By correlating the PMT's location with subsurface LRZ pings, the Zo Math Engine calculates exactly which 1-meter tile received water. If a Basic Tier (20m) user attempts to zoom in, the PMT's underlying high-fidelity data triggers the "Resolution Pop," initiating a pricing funnel for the Enterprise upgrade by showcasing the granular insight currently being "audited" in the background.
- **9-Axis IMU (The "Crabbing" & Structural Sentry):** A **Bosch BNO055** Inertial Measurement Unit continuously monitors vibration harmonics and 3D orientation.
  - *Diagnostic Intelligence:* It detects **"Crabbing"**—a dangerous condition where a tower's drive motor slips or stalls in deep mud, causing the massive steel span to bow and drift out of alignment. If crabbing or abnormal vibration is detected, the PMT alerts the Hub, which can immediately command the **PFA (Pressure & Flow Anchor)** to execute a "Soft-Stop" of the well pump, preventing catastrophic, $80,000+ structural collapses.

3. Non-Invasive Hydraulic Flow Stack (The Audit Engine)

The hydraulic flow stack is the primary engine for water rights verification and state-level regulatory compliance.

- **Ultrasonic Transit-Time Transducers:** Utilizes a **Badger Meter TFX-5000** clamp-on transducer pair.
  - *Physics of Flow:* These sensors utilize "Transit-Time" logic, measuring the nanosecond difference between ultrasonic pulses traveling upstream vs. downstream. This

difference is directly proportional to the water's flow velocity.

- *The "Cut-Less" Advantage:* Because these clamp to the *outside* of the 8" main pipe, they require zero pipe cutting or downtime. Most importantly, they ensure **zero pressure drop** in the hydraulic system. Unlike invasive paddle-wheel meters that create drag, this non-invasive approach preserves the energy efficiency of the well pump, saving the farmer thousands in seasonal energy costs.
- *Legal Certification:* The system provides ±1.0% flow accuracy, meeting the "Gold Standard" required for verified water use reporting to the State Engineer and securing long-term water rights through empirical proof.

4. Edge Processing & Winter Hibernation Logic

- **Cortex-M4 Processing Sled:** Features an **ATSAMD51** processing sled (sourced via Digi-Key). It buffers 1-second interval flow data and GNSS coordinates, applying a localized Kalman Filter to the IMU data to smooth out the intense vibration noise of the pivot spans.
- **Comms (Penetrating the Water Curtain):** Transmits via a **High-Gain BLE 5.0 (Long Range Mode)** antenna. It is specifically tuned with Coded PHY to penetrate the dense "water curtain" created by the pivot's nozzles and the massive steel interference of the span, ensuring a reliable 60-second handshake with the field's VFA anchor.
- **Winter Hibernation & "Warm Start":** Powered by an integrated **10W Solar Lid + LiFePO4 Buffer** from Renogy. To survive the 120-day SLV winter dormancy under 2 feet of snow, the PMT includes a **Saft LS14500 LiSOCl2 5yr Hibernation Pack**.
  - *RTC Maintenance:* This primary cell keeps the GNSS Real-Time Clock alive all winter. This ensures that when the pivot is first powered in the spring, it achieves a "Warm Start" GNSS lock in under 5 seconds, providing an unbroken audit trail for the season's first gallon.

5. Hyper-Granular BOM & Subdistrict 1 Project Costs (1,280 Units)

This ledger deconstructs the hardware costs for the initial 1,280-unit rollout, utilizing the high-volume industrial wholesale discounts detailed in the procurement ledgers.

Category	Component Description	Supplier	Part # / Type	Unit Cost	Ext. Cost
Housing	IP67 UV-Polycarbonate Puck	Polycase	WP-21F	$45.00	$45.00
Mounting	304-SS Band-It Straps (x2)	McMaster	5530K34	$12.50	$12.50

Mounting	Neoprene Friction Pad (Anti-Slip)	McMaster	8637K32	$5.50	$5.50
Computing	Cortex-M4 Processing Sled	Digi-Key	ATSAMD51	$65.00	$65.00
Position	u-blox ZED-F9P RTK GNSS	SparkFun	GPS-15136	$140.00	$140.00
Position	9-Axis IMU (Vibration/Tilt)	Bosch	BNO055	$32.00	$32.00
Hydraulic	Ultrasonic Transit-Time Pair	Badger Meter	TFX-5000	$648.00	$648.00
Power	10W Solar Lid + LiFePO4 Buffer	Renogy	Cust-10W	$95.00	$95.00
Power	LiSOCl2 5yr Hibernation Pack	Saft	LS14500	$25.00	$25.00
Fasteners	SS M4 Security Screws (x4)	McMaster	Security-M4	$2.00	$2.00
Radio	High-Gain BLE Whip Antenna	Linx	ANT-BLE	$30.00	$30.00
TOTAL	**Per Unit Hardware Cost**				**$1,100.00**

Total Subdistrict 1 Project Financials (1,280 Units):

- **Hardware Subtotal:** $1,408,000
- **Calibration & Field Audit:** $57,440 *(The Audit Protocol: Covers the specialized crew that cross-verifies every PMT against a portable "Master Meter" in the first 48 hours—a mandatory requirement for legally defensible Water Court reporting).*
- **Labor (Installation):** $100,000 *(The "Band-It Blitz": Calculated at 2 hours per unit, utilizing specialized boom trucks to reach the pivot spans safely and perform precision cleaning for ultrasonic coupling).*
- **TOTAL PROJECT COST: $1,565,440**

6. Strategic Value & Legal Defensibility

By deploying the PMT at this scale, FarmSense moves the needle from "estimated water use" to "audited water reality."

- **Water Court Integrity:** In the event of an aquifer depletion dispute, the PMT's unbroken, ±1.0% accurate log serves as the absolute "Gold Standard" of evidence, proving that every

gallon was applied exactly where the Oracle Map Manager and Zo Scientist Engine calculated it was needed.