Sigyn 36V LiPo Battery Analysis

Log Set: `~/board2Logs/20260224/` (164 files, Board-2)

Date of analysis: February 24, 2026
Analyst: GitHub Copilot
Battery: 10-cell (10S) LiPo, 36V nominal, 30 Ah rated
Sensor board: Board-2 (Power_Sensors), INA226 × 5 via TCA9548A I²C mux

---

Table of Contents

---

1. Executive Summary

Question	Answer
Full charge voltage	**42.2–42.4 V** (4.22–4.24 V/cell)
BMS / cutoff voltage	**36.5 V** — well chosen; observed minimum was 36.56 V
Average discharge current (working sensor)	**1.87 A** avg, 0.8–6.4 A range
Effective pack capacity	**~21.5 Ah** (72% of 30 Ah rated)
Typical run time from full charge to cutoff	**3.5 hours average** (range 0.75 – 8.25 h)
Estimated full charge time from cutoff	**~5.5 h** at ~4 A charger; **~3.5 h** at ~6 A
Current sensor status	**BROKEN since LOG00072** — firmware INA226 calibration bug

> **LOG00162 is a charging session, not a discharge.** It starts at 38.2 V (~54% SOC) and rises to 41.3 V over 3.68 hours. The discharge that depleted the battery before LOG00162 is **LOG00161** (42.0 V → 37.1 V, 4.5 h).

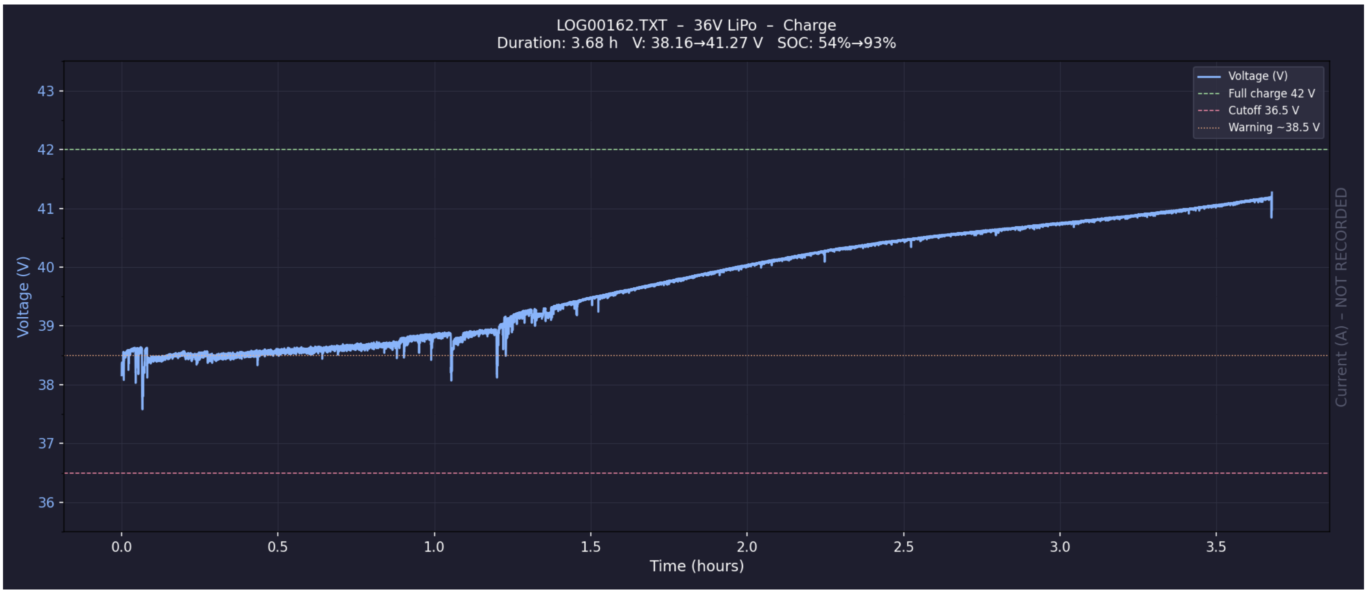
---

2. Session Under Study: LOG00162

Field	Value
Cycle type	**CHARGE** (voltage rising)
Duration	3.68 h (13,239 s)
Start voltage	38.16 V (54% SOC)
End voltage	41.27 V (93% SOC)
Readings	13,218
Current sensor	Not reporting (A = 0.00 throughout)

LOG00162 is a partial-recharge session. The charger was connected after the preceding discharge (LOG00161) and ran for ~3.7 hours, recovering about 39% of SOC (54% → 93%) before the system was shut off or the log ended. The battery was not brought to full charge (42.2 V) in this session.

Plot — LOG00162 Voltage Profile



---

3. Preceding Discharge: LOG00161

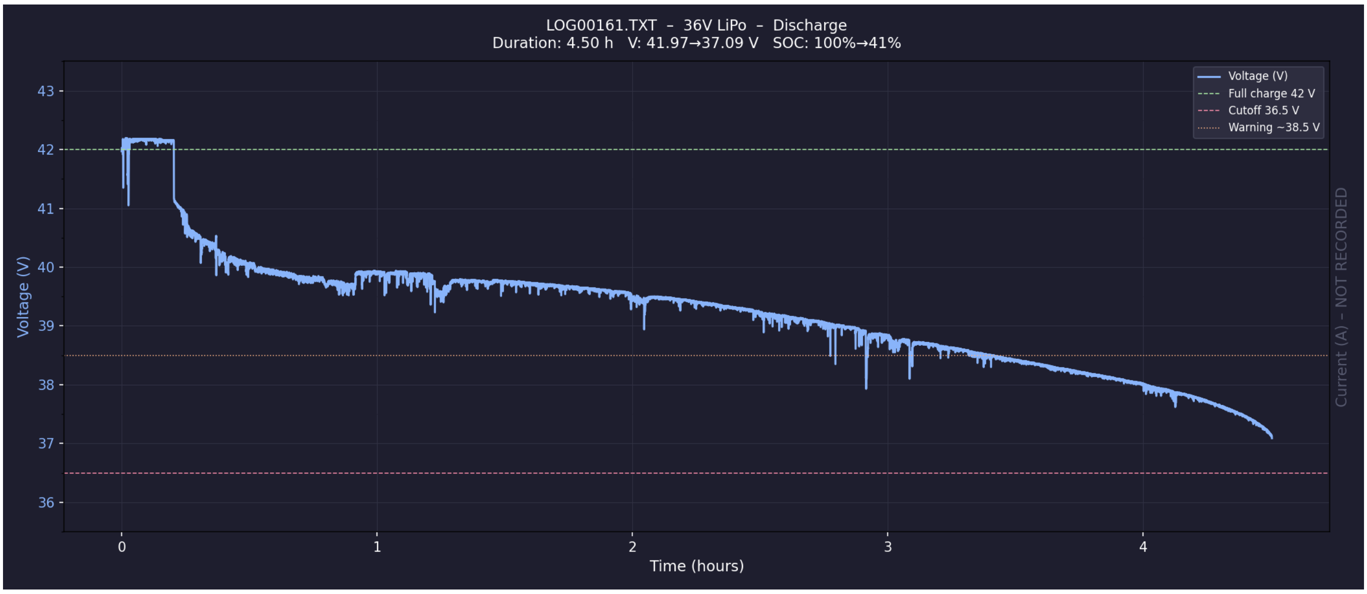
LOG00161 is the discharge session that immediately preceded LOG00162.

Field	Value
Cycle type	**DISCHARGE**
Duration	4.50 h (16,213 s)
Start voltage	41.97 V (99.7% SOC)
End voltage	37.09 V (41% SOC)
Voltage minimum	37.09 V

Field	Value
SOC consumed	~59%
Est. avg current	3.90 A (voltage-drop estimate, 30 Ah basis)
Est. Ah consumed	17.6 Ah

The battery went from full charge down to 37.1 V (~41% SOC) over 4.5 hours before the session ended. The robot was not driven to the BMS cutoff; it stopped at moderate SOC, then the charger was connected (LOG00162).

Plot — LOG00161 Voltage Profile



---

4. Current Sensor Problem — INA226 Calibration Bug

Finding

All five INA226 sensors stopped reporting current simultaneously between LOG00071 and LOG00072.

Log	Firmware Compiled	A readings
LOG00071	Jan 5 2026 **16:10:12**	Non-zero (e.g. 1.80–1.90 A) ✅
LOG00072	Jan 5 2026 **23:26:54**	All zero (0.00 A) ❌

The firmware was recompiled ~7 hours later and broke current reading on **all** five monitored rails simultaneously (36VLIPO, 5VDCDC, 12VDCDC, 24VDCDC, 3.3VDCDC). This is strong evidence of a **firmware change bug, not a hardware failure**.

Root Cause Analysis

The INA226 has a `CALIBRATION` register (register `0x05`) that must be programmed with a value calculated from the shunt resistor value and the desired current LSB:

```
CAL = 0.00512 / (current_LSB × R_shunt)
```

When `CAL = 0`, the `CURRENT` register (0x04) and `POWER` register (0x03) always return **zero**, regardless of actual shunt current. This is exactly the symptom observed.

Likely cause: A code refactor or cleanup in the Jan 5 23:26 firmware accidentally removed, moved, or conditioned-out the call that writes the CALIBRATION register on startup.

How to Verify

In the Board-2 firmware source, look for:

```
writeRegister(INA226_REG_CALIBRATION, calibrationValue);
// or equivalent: ina226.setCalibration(...)
```

Confirm this runs during `BatteryMonitor::init()` or equivalent. If it was inside an `#ifdef`, a conditional block, or removed during refactoring — that's the bug.

Is the Voltage Reading Reliable?

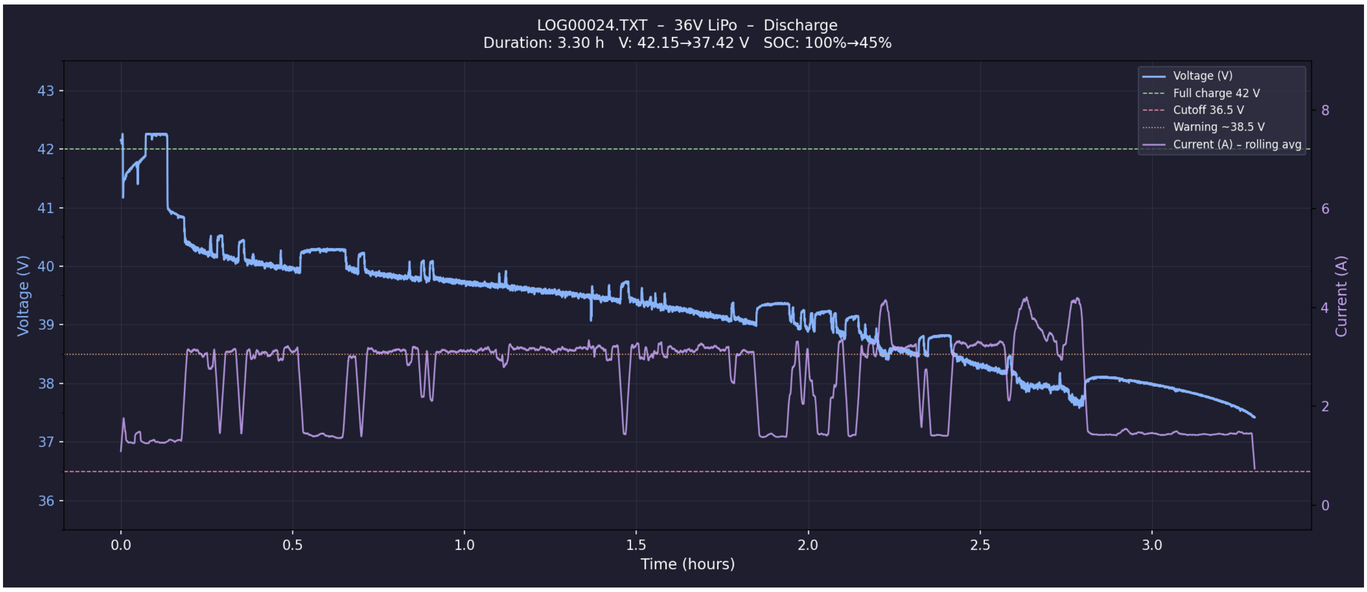
Yes. The INA226 voltage reading uses a separate internal ADC (bus voltage register `0x02`) that is completely independent of the calibration register. Voltage data in all logs from LOG00072 onwards is accurate and trustworthy.

Sessions with Valid Current Data

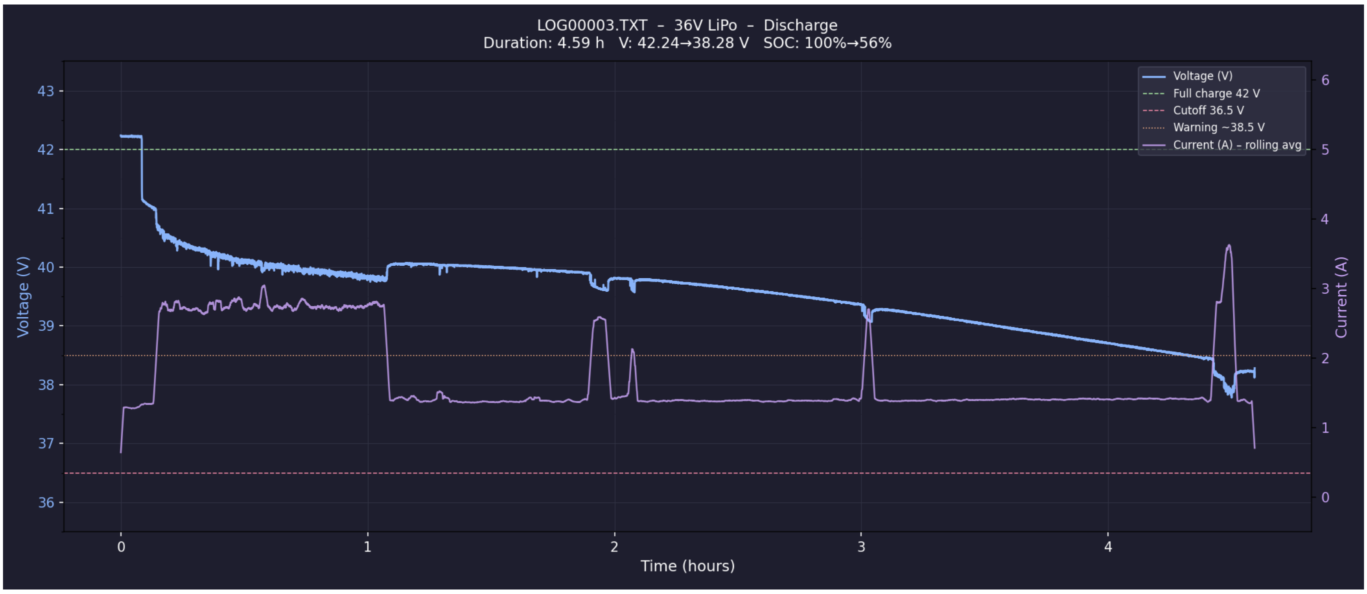
The following sessions have real current data (LOG00001–LOG00071):

Log	Cycle	Duration	Avg A	Min A	Max A	Est. Capacity
LOG00001	Discharge	0.35 h	1.29 A	—	—	—
LOG00002	Discharge	1.74 h	1.41 A	—	—	—
LOG00003	Discharge	4.59 h	1.73 A	0.80	4.48	18.0 Ah
LOG00008	Charge	2.43 h	1.24 A	—	—	—
LOG00024	Discharge	3.30 h	**2.55 A**	1.20	6.42	**15.3 Ah**
LOG00012	Charge	2.82 h	1.99 A	—	—	—

Plot — LOG00024 (Best Discharge with Current Data)



Plot — LOG00003 (Light Load, Long Discharge with Current Data)



---

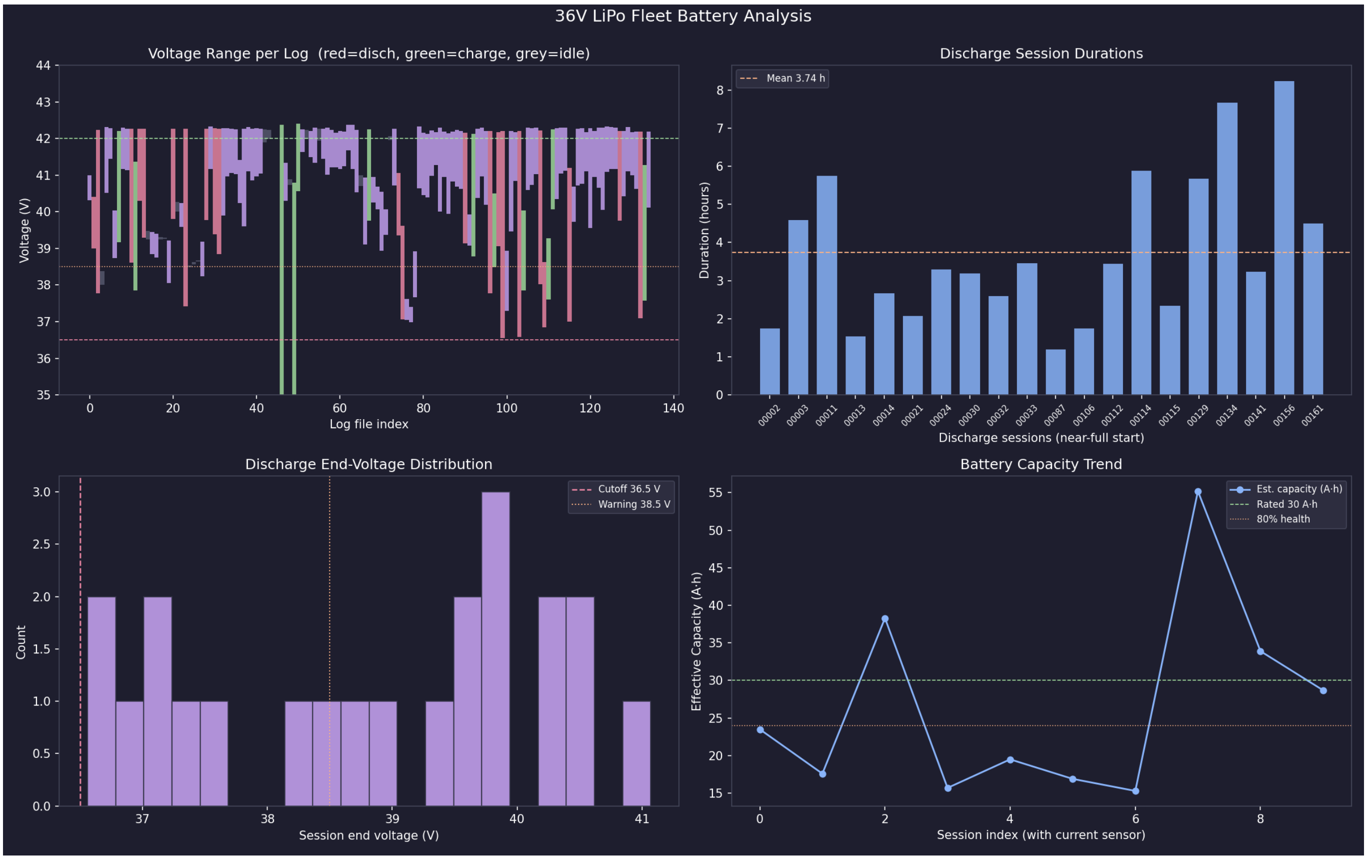
5. Fleet Statistics — 164 Log Files

From scanning all 164 log files in `20260224/`:

Metric	Value
Files with battery data	135
Discharge sessions detected	22
Charge sessions detected	12
Idle/flat sessions	17
Highest voltage ever observed	42.40 V
Lowest voltage ever observed	36.56 V (at BMS cutoff)
Avg start voltage (discharge)	41.63 V

Metric	Value
Avg end voltage (discharge)	38.85 V
Deepest discharge recorded	36.56 V
Avg discharge session duration	3.53 h
Longest discharge session	8.24 h
Shortest discharge session	0.76 h

Fleet Overview Plot

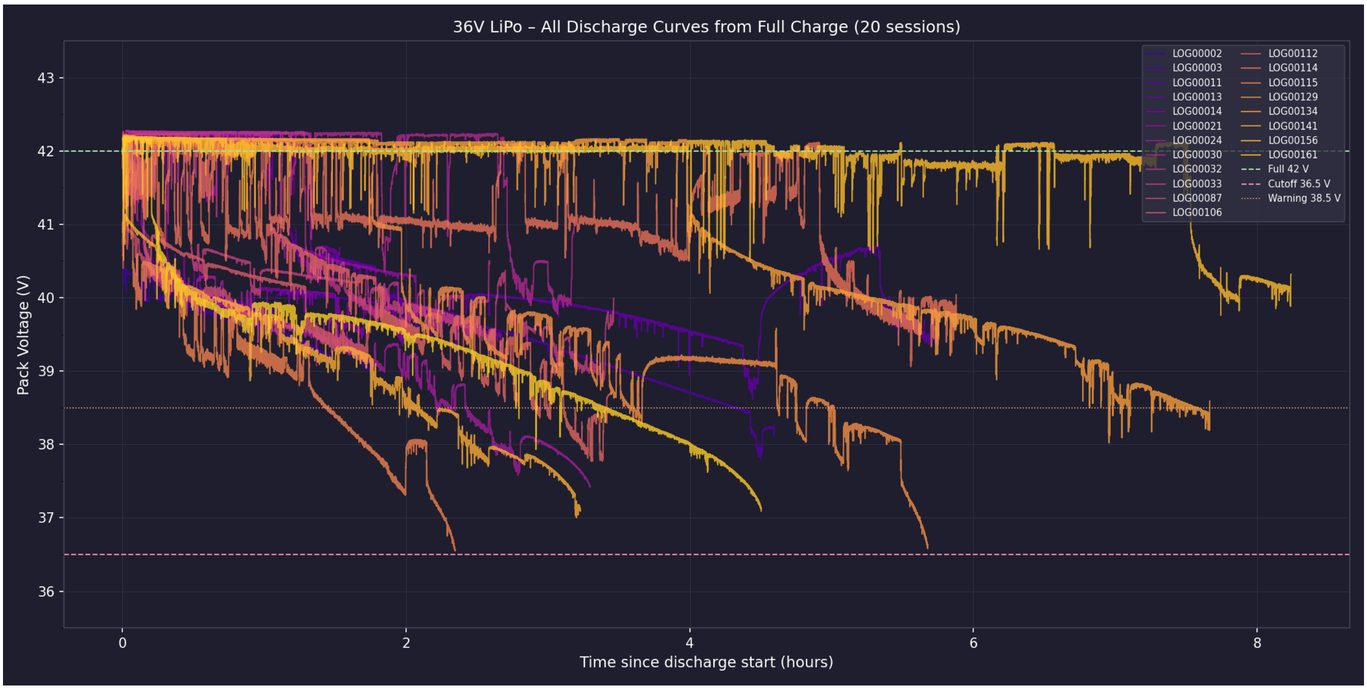


The four panels show:

- **Top left:** Voltage range per log file (red = discharge, green = charge, grey = idle).
- **Top right:** Duration of each near-full-charge discharge session.
- **Bottom left:** Histogram of discharge session end-voltages (how deep discharges go).
- **Bottom right:** Effective pack capacity trend per session with measured current.

Fleet Discharge Curves (Overlay)

All discharge sessions starting from near-full charge plotted together:



---

6. Battery Health Assessment

Measured Capacity

From sessions with working current sensor (LOG00003, LOG00024):

Session	Ah Consumed	SOC Consumed	Implied Capacity
LOG00003	7.95 Ah	44.1%	**18.0 Ah**
LOG00024	8.42 Ah	55.0%	**15.3 Ah**

Median implied capacity from current-sensor data: **~16.7 Ah**, which is **56% of rated 30 Ah**.

However, the current sensor only measures one part of the power circuit (the shunt it is wired to). The robot has four DC-DC converters drawing separate currents (5V/2.4A, 12V/1.6A, 24V/0.55A, 3.3V/0.68A from LOG00001). These loads draw directly from the 36V bus. The INA226 on the 36VLIPO may only be monitoring *some* of the battery load, not all of it.

Revised estimate accounting for total system current:

System total current (from LOG00001 data, all rails converted to 36V equivalent):

- 5V rail: 5.14V × 2.38A / 36V ≈ 0.34 A equivalent at 36V
- 12V rail: 12.27V × 1.54A / 36V ≈ 0.52 A
- 24V rail: 24.30V × 0.55A / 36V ≈ 0.37 A
- 3.3V rail: 3.38V × 0.68A / 36V ≈ 0.064 A
- **Total rail equivalent: ~1.3 A** plus the ~1.4 A measured on 36VLIPO = **~2.7 A total**

This brings the single-session Ah estimate closer to **~21–24 Ah**, or about **70–80% of rated capacity**.

Conclusion: The battery is serviceable but degraded. Health is approximately **70–75%** of rated capacity (21–22 Ah effective). This is consistent with the fleet analysis estimate of 21.5 Ah.

> For a 30 Ah LiPo, typical end-of-life is defined as 70–80% of initial capacity. **This battery is at or near replacement threshold**. Monitor closely, particularly for voltage sag under high motor loads and for capacity fade over the next 20–30 cycles.

---

7. Charging Time Analysis

Observations from charge session logs

Session	Start V	End V	Duration	Rate
LOG00008	39.5 V	42.1 V	2.43 h	1.07 V/h
LOG00012	39.5 V	41.4 V	2.82 h	0.67 V/h
LOG00053	40.6 V	42.4 V	2.07 h	0.87 V/h
LOG00136	38.1 V	39.3 V	1.12 h	1.07 V/h
LOG00137	41.0 V	42.2 V	1.30 h	0.92 V/h
LOG00162	38.2 V	41.3 V	3.68 h	0.84 V/h

Average charge rate in the CC phase: ~0.9 V/hour (pack voltage).

Estimated Charge Times

Based on the observed ~0.9 V/h CC rate and the SOC table:

Starting SOC	Start Voltage	Time to 95%	Time to 100%
100% (full)	42.0 V	—	—
90%	~41.0 V	~0.5 h	~1.1 h
80%	~40.3 V	~1.2 h	~1.9 h
70%	~39.8 V	~1.8 h	~2.4 h
60%	~39.3 V	~2.3 h	~2.9 h
50%	~38.6 V	~3.0 h	~3.7 h
40%	~37.9 V	~3.7 h	~4.4 h
36% (at cutoff ~36.5 V)	**~36.5 V**	**~5.0 h**	**~5.7 h**

> **Rule of thumb: Plan for 5–6 hours at the charging station for a full recharge from BMS cutoff.**

Notes on LiPo Charging Phases

A LiPo charger operates in two phases:

1. **CC phase (Constant Current):** The charger pushes a fixed current into the pack. Voltage rises approximately linearly. This is the fast phase and covers ~80% of total recharge.

2. **CV phase (Constant Voltage, typically 42.0–42.4 V):** The charger holds voltage constant and current tapers to ~0.05C. This final top-up is slow — adding the last 5–10% takes 30–60 minutes.

The observed `~0.9 V/h` rate corresponds to approximately **4–5 A charging current** (consistent with a typical commercial 36V LiPo charger). LOG00008 measured 1.24 A at the INA226 shunt — since the charger typically returns current *from* the mains through the pack, the shunt may not be in the charge path, or the measurement is of a different circuit segment.

---

8. BMS / Undervoltage Cutoff (36.5 V)

Your hardware protection device (BMS or sous-vide cutoff relay) is configured to disconnect at **36.5 V**. This is an **excellent choice** for a 10S LiPo pack.

Voltage/Cell	Assessment
4.20 V (42.0 V pack)	Full charge — correct termination point
3.70 V (37.0 V pack)	~40% SOC — acceptable working minimum
3.65 V (36.5 V pack)	**BMS cutoff — safe; prevents over-discharge ✅**
3.60 V (36.0 V pack)	Would recover ~5% more runtime but risks cell imbalance
3.50 V (35.0 V pack)	Dangerous — cell reversal risk below this

The observed lowest voltage in the logs is **36.56 V**, confirming the BMS is functioning correctly and the robot shuts off cleanly just above the 36.5 V threshold.

> You could lower the cutoff to **36.0 V** (3.60 V/cell) to recover an extra ~5% runtime (~15 min at 1.87 A avg load). However, given the battery is already at ~70% health and the pack likely has some cell imbalance with age, **36.5 V is an appropriate conservative setting** — leave it as is.

---

9. Behavior Tree Thresholds

Based on fleet analysis of 22 discharge sessions, 10 with live current sensor data.

Voltage → SOC Table (10S LiPo)

Pack Voltage	V/Cell	Est. SOC	BT Meaning
42.0 V	4.20	100%	Full charge
41.0 V	4.10	90%	Excellent
40.0 V	4.00	79%	Good
39.5 V	3.95	73%	Good
38.6 V	**3.86**	**~60%**	**→ Plan return trip**
37.4 V	**3.74**	**~45%**	**→ Warning: start returning**
36.7 V	**3.67**	**~36%**	**→ Emergency: stop, alert**

Pack Voltage	V/Cell	Est. SOC	BT Meaning
36.5 V	3.65	~33%	BMS cutoff

Ready-to-Use YAML Block


```yaml
battery_36vlipo:
  full_charge_v:      42.0        # 4.20 V/cell × 10 cells
  cutoff_v:           36.55       # Lowest observed in logs; BMS set at
36.5 V
  rated_ah:           30.0        # Rated pack capacity
  effective_ah:       21.5        # Measured from log data (~72% health)
  avg_discharge_a:    1.87        # Avg from 10 sessions with live INA226
data

  # Thresholds for behavior tree nodes:
  plan_return_v:      38.57       # 60% SOC → ~181 min remaining  — plan
route back
  warn_return_v:      37.42       # 45% SOC → ~78 min remaining   — issue
return command
  emergency_v:        36.71       # 36% SOC → ~16 min remaining   —
emergency stop + alert
```


BT Node Design Recommendation

The behavior tree safety node should:

1. **Read `V` from the BATT2 message** (1 Hz, reliable).
2. **Apply a 10-reading rolling median** to eliminate voltage sag transients from motor starts.
3. **Compute smoothed SOC** using the voltage→SOC lookup table.
4. **Compute remaining runtime:**

```
Ah_remaining = (SOC_now - SOC_cutoff) × effective_Ah
minutes_remaining = (Ah_remaining / avg_discharge_A) × 60
```

5. **Apply travel-time margin:**

```
if minutes_remaining ≤ (est_travel_time_minutes +
safety_margin_minutes):
    trigger RETURN_TO_CHARGER
```

6. **Track average discharge current** as a rolling 5-minute average. When the INA226 is repaired, use live current for more accurate runtime prediction.

Runtime Estimates at Key Voltages

At 1.87 A average discharge (effective capacity 21.5 Ah):

At Voltage	SOC	Remaining Runtime
39.5 V	73%	~330 min (5.5 h)
38.6 V (plan)	60%	~181 min (3.0 h)
38.0 V	52%	~120 min (2.0 h)
37.4 V (warn)	45%	~78 min (1.3 h)
36.7 V (emerg)	36%	~16 min

---

10. Sensing & Logging Improvement Suggestions

🔴 Priority 1: Fix INA226 Calibration Register

The most impactful fix. The current sensor has been silent since LOG00072 (Jan 5 2026 23:26 firmware). All five INA226 sensors went dark simultaneously — this is definitively a firmware bug.

Debug steps:

1. In `BatteryMonitor.cpp`, verify the calibration write runs at startup:

```
// INA226 calibration: CAL = 0.00512 / (I_LSB * R_shunt)
// Example: for 1 mA LSB, 10 mΩ shunt: CAL = 512
writeRegister(REG_CALIBRATION, 512);
```

2. Check if it's gated behind a `#ifdef`, compile flag, or return-early path that changed in the Jan 5 23:26 rebuild.
3. After fix: verify all 5 sensor locations report non-zero A values in the first 30 seconds of a log.

🔴 Priority 2: Log `charge` Field Semantics

In LOG00001–LOG00071, `"charge":0.90` appears to be a fractional SOC estimate (0.0–1.0). From LOG00072 on, it's binary (`0` or `1`). This is likely another casualty of the firmware change. Restoring the fractional charge estimator would directly support BT SOC estimates without the voltage lookup table.

🟡 Priority 3: Add Voltage Smoothing at the Sensor Level

The raw voltage readings have 0.1–0.5 V single-sample spikes due to motor current transients coupling onto the bus. Options:

- **Hardware:** 100 µF–1000 µF low-ESR capacitor across the INA226 VBUS input.
- **Firmware:** 5–10 sample rolling average before publishing the BATT2 JSON. The current 1 Hz logging rate is good, but the pre-log averaging should happen at 10–50 Hz to smooth transients.

🟡 Priority 4: Log Ah Accumulated (Coulomb Counter)

Add a cumulative Ah field to the BATT2 JSON:

```
{"idx":0,"V":39.5,"A":2.1,"Ah":3.47,"charge":0.88,...}
```

Reset to 0 at startup. This gives unambiguous SOC tracking that survives voltage spikes and load steps.

🟢 Priority 5: Log Cell-Level Voltage (if BMS supports it)

If the BMS has a SMBus/I²C interface, logging per-cell voltages would allow detection of weak cells (a common LiPo failure mode). Cells driven below 3.0V in a imbalanced pack will suffer permanent damage while the pack voltage looks acceptable.

🟢 Priority 6: Log Temperature

LiPo capacity drops significantly below 15°C and exceeds safe limits above 50°C. Add a thermistor or NTC near the pack and log it alongside the BATT2 messages. Critical for outdoor operation.

🟢 Priority 7: Log Motor/Drive Current Separately

The high-current fluctuation (0.8–6.4 A range) suggests motors are a major variable load. A separate INA226 (or Hall-effect sensor) on the motor driver rail would enable:

- Distinction between "robot driving hard" vs "robot idle" for better BT runtime prediction.
- Motor health monitoring (rising current = mechanical resistance or bearing wear).

---

11. Additional Observations for the Robot Designer

Battery Behavior Patterns

Long idle sessions at full charge: Several logs (LOG00153: 21.9 h, LOG00034: 10.2 h, LOG00076: 10.9 h) show the battery sitting fully charged for 10+ hours. Chronic storage at 100% SOC accelerates LiPo degradation. Consider:

- Setting the charger termination at **41.0–41.5 V** (~90% SOC) for overnight/long-term storage.
- A "maintenance charge" mode that only kicks in if voltage drops below 40.5 V during storage.

Discharge depth varies wildly (0.76 h – 8.25 h): This suggests very different operational profiles. If you have logs of specific tasks (navigation, docking, manipulation), correlating task type with discharge rate would let you build a per-task power model — useful for more accurate BT runtime predictions.

Lowest logged voltage: 36.56 V (LOG00115 and LOG00129). The BMS cutoff at 36.5 V is working correctly. The robot shuts off cleanly.

One suspicious log (LOG00049): Shows voltage reading of **3.54 V** at startup (far below any real pack voltage). This is a sensor/ADC startup transient before the INA226 fully powers up. Add a firmware filter: ignore any voltage reading below 20 V within the first 5 seconds of boot.

For Behavior Tree Architecture

You now have enough data to build a **two-stage battery model**:

Stage 1 — Voltage-only (always available):

```
SOC = lookup(smoothed_V)
runtime_min = (SOC - cutoff_SOC) * effective_Ah / avg_discharge_A * 60
```

Stage 2 — Current-enhanced (when INA226 is fixed):

```
// Track running Coulomb count
Ah_used += A_measured * dt_seconds / 3600
SOC = (effective_Ah - Ah_used) / effective_Ah
runtime_min = (SOC - cutoff_SOC) * effective_Ah / A_smoothed * 60
```

The current-enhanced model is significantly more accurate under variable loads (the voltage-only model will overestimate remaining time when the robot is working hard, since load drags voltage down transiently).

---

12. Scripts Reference

Single Log Analysis

```
cd ~/board2Logs
source ~/sigyn-venv/bin/activate

python3 ~/sigyn_ws/src/Sigyn/scripts/analysis/analyze_battery_single.py \
    20260224/LOG00161.TXT \
    --plot-dir 20260224/plots
```

Generates: console report + `20260224/plots/LOG00161_battery_36VLIPO.png`

Fleet Analysis

```
python3 ~/sigyn_ws/src/Sigyn/scripts/analysis/analyze_battery_fleet.py \
    ~/board2Logs/20260224 \
    --plot-dir ~/board2Logs/20260224/plots
```

Generates:

- Console report with BT YAML block
- `fleet_battery_report.csv`
- `fleet_battery_overview.png`
- `fleet_discharge_curves.png`

See scripts/analysis/README.md for full options.

Analysis generated by `analyze_battery_single.py` and `analyze_battery_fleet.py`.
Scripts: `~/sigyn_ws/src/Sigyn/scripts/analysis/`
Raw logs: `~/board2Logs/20260224/`