SURGE 2.0 ROBOTIC HAND

Interface Control Document

Document Number	AB-ICD-002
Revision	E
Date	August 4, 2026
Status	Electrical interface updated for Surge 2.0 PCBA; firmware functional feature set incorporated

Revision History

Rev	Date	Author	Description of Change
A	January 1, 2026	Jackson Heinz	Initial Release
B	May 1, 2026	Jackson Heinz	Clarifications on Manus Mode Enabled
C	June 23, 2026	J. Beens	Replaced electrical interface (power system) with Surge 2.0 PCBA characterization; added firmware-derived functional feature specifications; added MODBUS reference documents; section numbering consolidated
D	July 22, 2026	J. Beens	Added joint angle minimums and maximums in section 9.1.
E	August 4, 2026	J. Beens	Added internal connector pinouts for direct-to-hand power and signal connection. See new section 3.2.

1 System Overview

Product Name	Surge 2.0
Document Rev	E
Date	August 4, 2026
Prepared By	J. Beens
Reviewed By	Ryan Saavedra, Jason Beens, Samuel Woolfolk
Integration Platform	Multiple platforms; compatible with multi-axis robotic arms and humanoid platforms
Intended Use	General-purpose dexterous manipulation: industrial automation, research, prosthetics, and broad human-environment interaction

1.1 System Description

Surge 2.0 is a 6-degree-of-freedom robotic hand designed for humanoid and robotic-arm platforms, combining human-inspired dexterity with robust engineering to give robots reliable, practical interaction in real-world environments. It provides closed-loop motor control, an industrial host interface (MODBUS RTU over RS-485), a built-in grip library, comprehensive on-board safety and protection, full telemetry and diagnostics, and in-field firmware update.

1.2 Interface Summary

Power: 48 V DC nominal via M8 4-pin circular connector (Pin 1: Vcc, Pin 2: GND). Communication: RS-485 half-duplex (Pin 3: RS485_B, Pin 4: RS485_A). A single cable carries both power and communication.

1.3 Assumptions & Constraints

Host processor type, OS, and cable-harness configuration are determined by the integrating platform. The RS-485 interface supports multi-drop addressing for multiple hands on a shared bus (see Section 10); see the grounding note in Section 2 regarding the shared power/signal return.

1.4 Reference Documents

The following documents are referenced throughout this specification. The short tags in brackets are used for inline citations.

Table 1 - Reference Documents

Tag	Document	Version / Date
[RS]	Surge 2.0 MODBUS RTU Register Specification (protocol register map)	v1.0, 22 Jun 2026
[AG]	Surge 2.0 MODBUS RTU Applications Guide (host-side integration guidance and examples)	v1.0, 22 Jun 2026
[FWUP]	Surge 2.0 MODBUS RTU Firmware Update Application Note (host over-the-bus update procedure)	v1.0, 22 Jun 2026

2 Electrical Interface

The Surge 2.0 hand operates from a wide-range DC input behind an active hot-swap protection front end. This allows operation of 24-volt, 36-volt, and 48-volt nominal systems. Additionally, the hand will operate at lower voltages with derating speed and power. This allows support for sagging or failing battery systems or experimentation with less conventional power systems.

2.1 Input Voltage Ratings

Table 2 - Input Voltage Ratings

Parameter	Specification	Notes
Nominal input voltage	48 VDC	Recommended operating point
Logic / communications operating range	9 – 60 VDC	Boots, maintains RS-485 comms, reports full telemetry
Full finger operation	24 – 60 VDC	Full speed and grip force
Derated finger operation	12 – 24 VDC	Reduced speed/power; derating application-dependent
Absolute maximum operating voltage	65 VDC	Do not exceed. Operation above 60 V is outside the validated range. Hand will power off above approx. 65 V.
Transient (spike) survival	Up to 100 V	Non-operating; survived via input protection (§2.2)

2.2 Input Protection (Hot-Swap Front End)

Table 3 - Input Protection

Parameter	Value / Specification
Startup / inrush current limit	2 A maximum (actively limited by hot-swap controller)
Over-voltage disconnect	Input disabled above 67 V
Disconnect device	100 V MOSFET
Reverse-polarity protection	Provided
Transient survival	Up to 100 V
RS-485 line protection	TVS diodes on data lines (A/B) plus common-mode choke

The 67 V over-voltage disconnect is the active trip for sustained over-voltage; the 100 V figure is the transient survival ceiling. These are distinct mechanisms.

2.3 Idle Power Consumption

Typical input current and power with the hand powered, communicating, and not actuating:

Table 4 - Idle Power Consumption

Input Voltage	Idle Current	Idle Power
9 V	25.5 mA	0.23 W
12 V	23.3 mA	0.28 W
24 V	13.6 mA	0.33 W
36 V	40.3 mA	1.45 W
48 V	26.4 mA	1.27 W
60 V	26.6 mA	1.60 W

Idle draw is lowest in the pass-through range (≤24 V). Above the ~28 V transition the motor-rail regulator adds a fixed overhead, placing idle power in the regulated range at approximately 1.3–1.6 W.

2.4 Active Power Envelope

Finger motion is typically strongly duty-cycled: each actuation is a short current burst that returns to near-idle between movements, so peak and RMS currents differ by roughly 3:1.

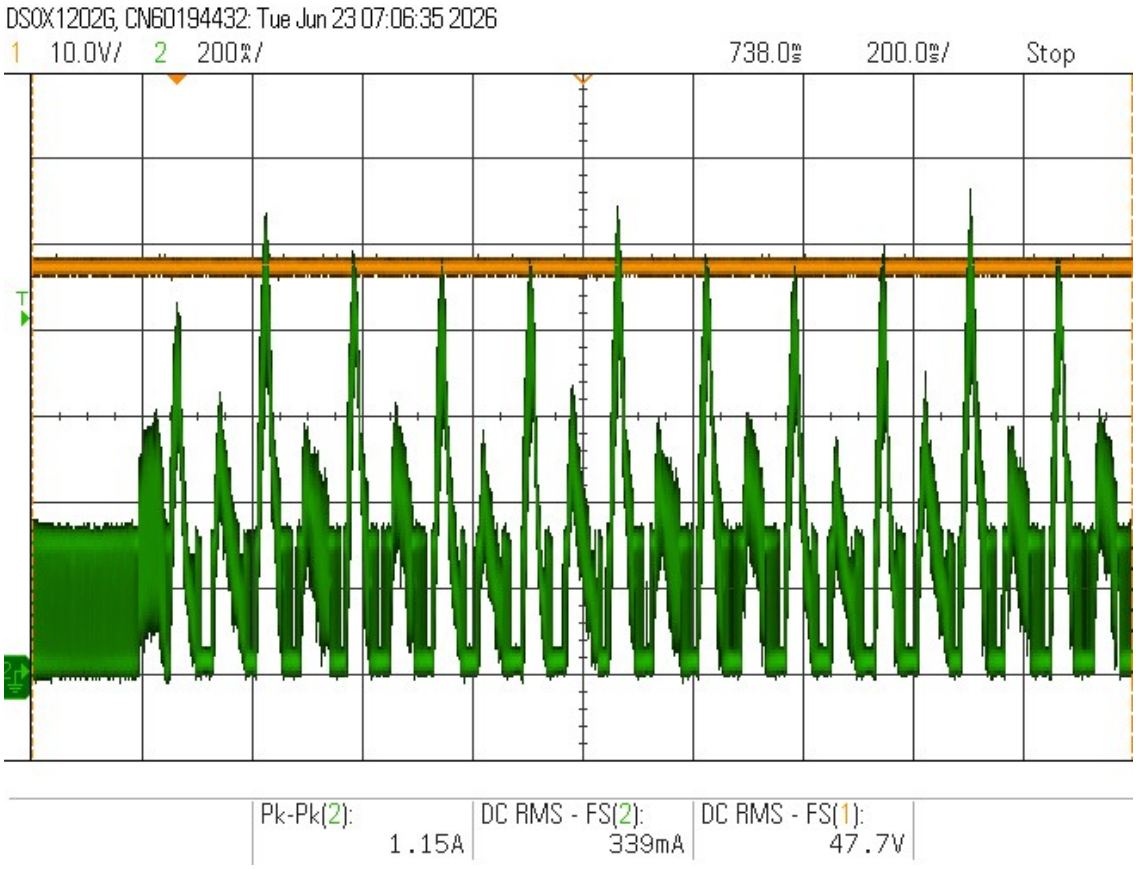

Figure 1 - Current and voltage example of fast indexing (Demo sequence)

Representative values during aggressive, continuous multi-finger motion
(fast indexing movement of the demonstration sequence):

Table 5 - Hand Loading

Input Voltage	Peak Input Current	RMS Input Current	Avg Input Power
24 V	~1.9 A	~0.45 A	~11 W
48 V	~1.1 A	~0.37 A	~18 W
60 V	~0.9 A	~0.26 A	~15 W

Parameter	Value / Specification
Per-motor stall current	On stall, the driver enters a regulated constant-current hold or shuts down to protect the winding and supply.
Load-current scaling	In the regulated range, motor power is held constant; input current therefore scales inversely with input voltage. Peak input current is highest at the bottom of the operating range.

2.5 Power Supply Selection

A 48 VDC supply is recommended for most installations.

- Peak / instantaneous capability: provide for up to ~2 A (covers inrush and motion peaks). At 48–60 V, motion peaks stay below ~1.2 A.
- Continuous / thermal load: average draw under heavy use is approximately 15–20 W.
- Operate at 48–60 V for hard duty cycles — keeps peak input current well under ~1.2 A and lets the regulator hold full motor voltage through droop. 24 V is idle-efficient but margin-poor under load.
- Power sequencing: none required (single power source).

Power Connector Type	M8 circular, 4-pin, A-coding, right-angle female (IEC 61076-2-104); M8×1.0 locking thread

3 Hand to Host Connection

3.1 Connecting at the Wrist Adapter

The following pinout applies to the Surge wrist connector (M8, 4-pin) and the mating cable (FTDI USB-RS485-WE or equivalent). Use this connection scheme for cables which run externally to the robotic arm. This connector is mounted on the wrist adapter as shown in Figure 2.

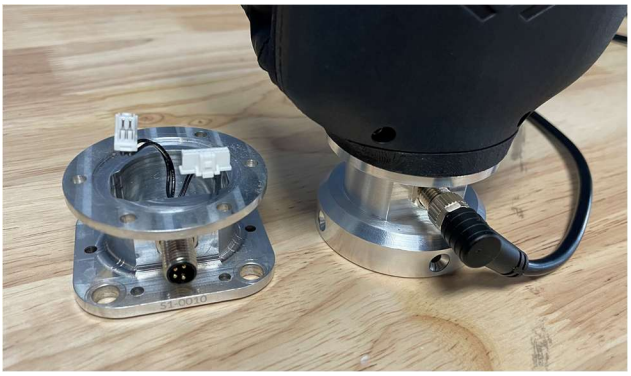

Figure 2 - Wrist Adapter (left) and Hand with Adapter Mounted (right)

Table 6 - Wrist Adapter Connector Pinout (looking into the connector)

Pin #	Signal Name	Wire Color (Cable) / Notes
Pin 1	Vcc	Blue — Power supply positive
Pin 2	GND	Brown — Power supply ground / common return
Pin 3	RS485_B	Black — RS-485 Data B (−)
Pin 4	RS485_A	White — RS-485 Data A (+)

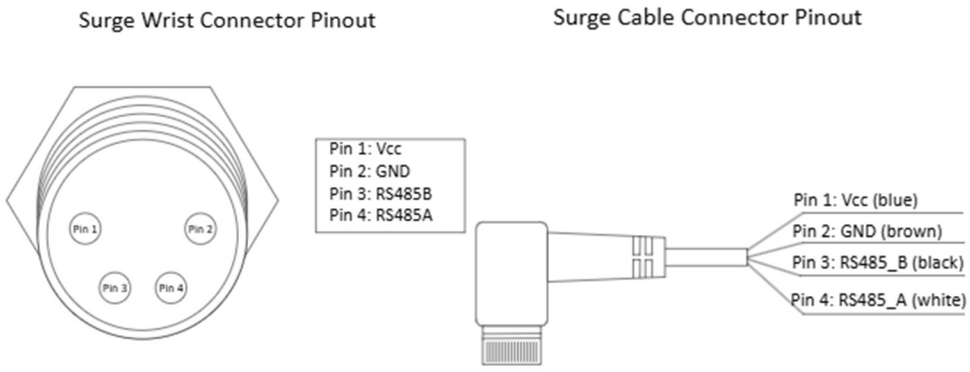

Figure 3 - Wrist Connector Pinout Surge Side Looking into Connector (left) Cable Color Code (right)

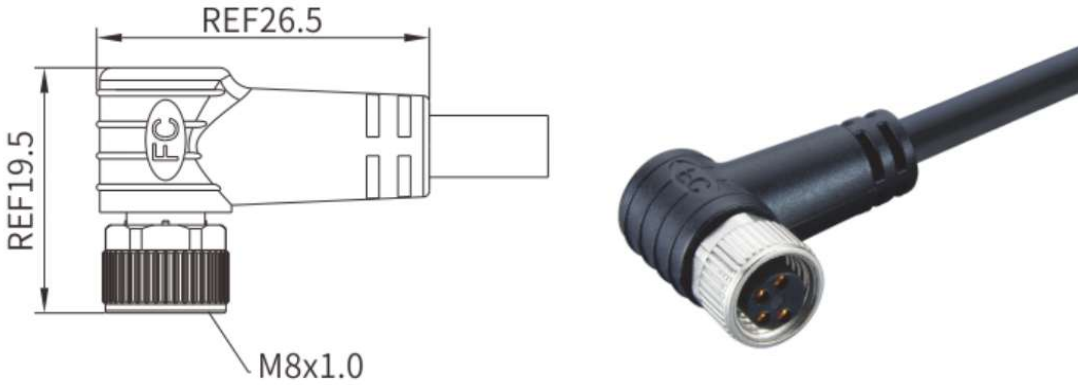

Figure 4 -Mating cable connector, M8 right-angle female (M8×1.0), reference dimensions in mm

Grounding note: the power return (GND) and the RS-485 signal reference share a common conductor. The RS-485 interface is therefore not galvanically isolated from power ground. On multi-drop installations, plan bus topology and grounding accordingly.

3.2 Connecting at the Hand Interface (for internally routed power and signal)

For full integration with robotic arms, the power and communications connectors can be accessed at the Surge hand interface. These direct interface connectors deliver power and communications to the hand and allow the robot integrator to route all control and power cabling internal to the robot chassis. The power and communication connectors are identified in Figure 5, along with the Pin 1 reference for each connector.

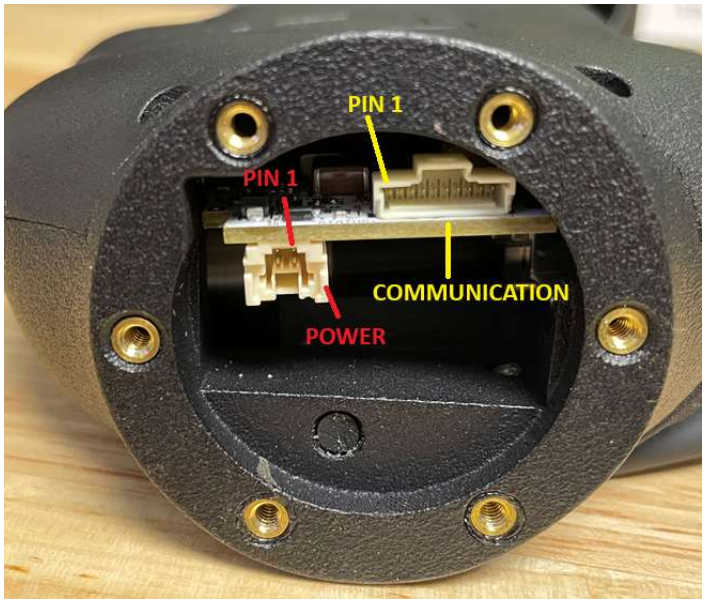

Figure 5 - Direct Interface Connectors Looking into Hand

3.2.1 Direct Interface Connector – Power

The direct interface connector for power provides the hand with the power needed to perform manipulation and provide communications. This connector is a two-wire connector, and both wires must be connected to the host power supply appropriately.

Table 7 - Internal Power Connector Mating Part Numbers

Description	Manufacturer	Manufacturer Part Number	Digikey Part Number
Connector Housing	JST	ZER-02V-S	455-2411-ND
Power wire with crimped Pin (4”)	JST	ASZESZE26K102	455-4202-ND

Table 8 - Internal Power Connector Pinout

Pin #	Signal Name	Notes
Pin 1	Ground	Connect to system ground
Pin 2	Power	Hand power supply connection, connect to host DC supply

3.2.2 Direct Interface Connector – Communications

The direct interface connector for communications provides the hand with the RS-485 network access over which the hand can be controlled. This connector is a ten-wire connector. At least three contacts must be populated on this connector. Pins 4 and 5 mut be populated, and at least one of Pins 3 and 4 must be connected to system ground. Reserved pins are to be left unconnected.

Table 9 - Internal Power Connector Mating Part Numbers

Description	Manufacturer	Manufacturer Part Number	Digikey Part Number
Connector Housing	Molex	5013301000	23-5013301000-ND
Black wire, 28 AWG, with crimped pin (11.8”)	Molex	0797581019	WM15697-ND

Table 10 - Internal Communications Connector Pinout

Pin #	Signal Name	Notes
Pin 1	Reserved	Leave unconnected
Pin 2	Reserved	Leave unconnected
Pin 3	Ground	Connect to system ground
Pin 4	RS-485 B	Network signal wire (negative)
Pin 5	RS-485 A	Network signal wire (positive)
Pin 6	Ground	Connect to system ground
Pin 7	Reserved	Leave unconnected
Pin 8	Reserved	Leave unconnected
Pin 9	Reserved	Leave unconnected
Pin 10	Reserved	Leave unconnected

4 Communication Interface

MODBUS RTU over RS-485 is the primary host interface (see Section 10 for the full functional description). The legacy AT-command text protocol remains available for backward compatibility. Full register-level protocol details are defined in the MODBUS RTU Register Specification [RS]; host-side integration guidance and worked examples are in the Applications Guide [AG].

Parameter	Value / Specification
Interface type	RS-485 (TIA-485-B) half-duplex, 2-wire
Protocol	MODBUS RTU
Protocol Version	Alt-Bionics Protocol v1.x
Bit rate	Host-configurable; 115200 bps default; 921600 bps maximum
Parity	Host-configurable; even parity default
Bus termination	On-board 120 Ω, firmware-enabled, disabled by default
Max cable length	3 meters
Connector / cable type	Surge side: M8 4-pin circular, A-coding, right-angle female (IEC 61076-2-104). Host side: FTDI USB-RS485-WE-1800-BT or equivalent RS-485 adapter.

5 Fault Handling

Over MODBUS, the structured, latching fault model is exposed in the FAULT registers defined in [RS] §6 (Status and Fault); see also Section 12.

6 Startup / Initialization / Shutdown

Parameter	Value / Specification
Boot time	~5 seconds after hand enable is issued to hand ready state.
Default state on power-up	Uninitialized. Hand state is validated during homing.
Required startup commands	Hand Enable, E-Stop Clear (if applicable). The hand will not move unless it is given explicit permission by the host through the Hand Enable command. Any E-Stop will persist until cleared, even across power removal events.
Power-on self-test	Non-blocking health-check covering supply rails, on-board sensors and memory, temperatures, and per-motor presence detection before declaring the hand ready.
“Ready” contract	A status bit signals when the hand is fully calibrated, self-tested, and ready to accept motion.
No-motion without command	All hand motion is gated by a hand-enable command, which must be issued before the device will perform its start-up homing sequence.
Automatic homing	Full factory calibration discovers each joint's reference and travel limits, validates them, and stores them in memory. Homing validates stored limits for quick startup, falling back to full calibration if validation fails.
Handedness auto-detection	Firmware automatically determines whether it is installed in a left or right hand.

6.1 Safe Shutdown Behavior

Place the hand into the open pose and remove power.

7 Mechanical Interface

Parameter	Value / Specification
Mounting interface / pattern	EN ISO 9409-1-50-4-M6 (industry standard); custom mounting adapters also available
Connector location	Wrist adapter, dorsal side. 90° right-angle M8 connector.
Cable strain relief	Recommended
Min bend radius (cable)	35 mm
Integration notes	Ensure the M8 cable is fully tightened when removing and attaching.

8 Environmental Limits

Parameter	Value / Specification
Recommended Operating temperature	-10 °C to +45 °C
Storage temperature	-20 °C to +60 °C
Humidity (operating)	5% to 95% RH, non-condensing
IP Rating	IP54 (unofficial)

9 Functional Overview (Firmware Feature Set)

The following sections specify the Surge 2.0 functional feature set as implemented in firmware (MODBUS register map, control stack, and platform services). Numeric thresholds are configuration defaults and may be tuned per build/platform revision. Register-level definitions for the MODBUS-exposed items below are in [RS].

Pillar	Highlights
Motion	6 independent joints; position control in degrees or normalized units; 11 collision-safe grip poses; user-defined frames and sequences
Grip	Per-finger force control (0–100%); adaptive press-and-hold; sensorless stall/contact detection
Host Interface	MODBUS RTU over RS-485; multi-hand addressing; full read telemetry and write control
Safety	E-stop, host-comms watchdog, hardware watchdog, per-motor I^2t thermal protection, power-rail and thermal fault monitoring
Telemetry	Live position, current, grip force, power rails, temperature; session and lifetime energy/runtime accounting
Serviceability	In-field firmware update over the host bus, signed and verified, with automatic rollback; reboot-cause reporting; link-health diagnostics
Configuration	Non-volatile, host-writable settings; auto-calibration; left/right handedness auto-detect; diagnostics console

10 Motion & Control

10.1 Six Degrees of Freedom

The hand actuates six independent joints in a fixed canonical order. Each joint is independently commandable and independently reported.

#	Joint	Travel	Minimum Joint Angle	Maximum Joint Angle
0	Index	Finger flex	−4.0°	92.0°
1	Middle	Finger flex	−4.0°	92.0°
2	Ring	Finger flex	−4.0°	92.0°
3	Pinky	Finger flex	−4.0°	92.0°
4	Thumb Flexion	Thumb flex	−14.0°	80.0°
5	Thumb Rotation	Thumb opposition	−28.0°	80.0°

The MODBUS interface provides a command to query the joint angle extremes for each hand. It is recommended that users of the joint angle commands request the joint angle extremes from the hand directly. (The MODBUS canonical order below differs from the legacy AT-interface letter codes.)

10.2 Position Control — Degrees or Normalized

- Degrees (1/100° resolution on the wire) — human-readable joint angles.
- Normalized (0–1) — abstracted closed-to-open position independent of mechanical limits.

Commands can target a single joint or all six in one atomic multi-joint update, with a per-joint “skip” option so the host can move a subset without disturbing the rest. Actual position is continuously reported back in both degrees and normalized units.

10.3 Grip Force Control (Per Finger)

Each finger supports an independently settable grip force from 0% to 100%. At 0% the finger reaches its stop and holds with no grip pressure; at 1–100% the finger presses into the object on contact/stall at a scaled engagement force, then settles into a low, steady holding current. Grip force is a live setting (immediate; not stored across reboot). Contact and grip quality are detected from motor current — no dedicated force sensor is required.

10.4 Grip Pose Library (11 Built-In Poses)

Eleven pre-programmed, collision-safe grip poses are built in; each automatically phases thumb and finger motion to avoid collisions. Each pose has a stable numeric ID, and a status channel reports whether the pose is in motion, complete, blocked, or invalid.

Pose	Description
open	All fingers extended, thumb abducted — neutral position
power	Power grip — fingers wrap, thumb secures
key c / key o	Key grip, closed / open
pinch c / pinch o	Precision pinch, closed / open
chuck c / chuck o	Three-finger chuck, closed / open
point	Index point
rest	Relaxed rest pose
midas	Shipping / storage pose

10.5 User-Defined Frames & Sequences

Operators can capture custom frames (named snapshots of all six joint angles) and chain them into sequences (multi-step animations with optional looping and per-step hold), stored in non-volatile memory.

11 Host Interface — MODBUS RTU over RS-485

The primary control and telemetry interface is MODBUS RTU over RS-485, an industrial-standard fieldbus. It supports the standard function codes for reading input/holding registers and writing single/multiple registers (FC03/04/06/16). The complete register map is defined in [RS]; worked host-side examples and design guidance are in [AG].

Parameter	Value / Specification
Multi-hand networking	Configurable slave/unit address (1–247) lets multiple hands share one RS-485 bus
Configurable link	Host-configurable baud rate and parity; on-board 120 Ω termination is firmware-enableable
Auto-clearing commands	Single-shot commands (enable, pose request, reboot, etc.) auto-clear after the firmware acts, giving the host positive confirmation
Protected destructive commands	Reboot and firmware-update commit require a key in the same transaction, preventing accidental triggering

12 Telemetry & Diagnostics

The following are exposed to the host via MODBUS input registers and/or the diagnostics console. Register addresses and encodings are defined in [RS] (§5 position feedback, §7 motor telemetry):

12.1 Motion & Grip Telemetry

- Actual joint position — degrees and normalized, per joint
- Per-joint motor current (mA)
- Per-joint grip intensity (engagement intensity after contact)
- Per-joint operational limits (min/max angle)
- Per-joint energy accumulated
- Pose status (in-motion / complete / blocked / invalid)

12.2 Power & Thermal Telemetry

- Input supply voltage and current
- Motor-bus voltage
- 5 V and 3.3 V logic-rail voltages; 5 V rail current
- MCU die temperature

12.3 Energy & Runtime Accounting

Per-motor and input-rail accounting in two scopes: Session — energy (mJ) and active time (ms) since boot, host-resettable per motor; Lifetime — cumulative energy (J) and active time (s) that persist across reboots and cannot be host-reset (useful for wear/maintenance tracking). Session and lifetime uptime are also reported.

12.4 Identity & Version

- 64-bit device GUID (unique per unit)
- Product code (with option bits, e.g. tactile sensing)
- Firmware version and hardware revision (hardware revision auto-detected)

12.5 Host-Link Health Diagnostics

A dedicated block of link-health counters supports field troubleshooting of the RS-485 connection: poll/response/transaction counts, dropped responses, TX-wedge recoveries, port resets, and UART error tallies (overrun, framing, noise, parity, CRC, transport).

13 Safety & Protection

Parameter	Value / Specification
Emergency stop (E-stop)	Host- or fault-triggered. Configurable, non-volatile response: hold current position or power down the motor rails. Latched across reboot until the host explicitly clears it. By design, E-stop never drives motion.
Host-communications watchdog	Detects a lost/silent host. If no valid transaction arrives within the configured timeout (10 ms–10 s, default 1 s), the firmware disables motion (default safe freeze) or runs the E-stop response. A status bit reports whether it is armed.
Hardware watchdog	Independent MCU watchdog resets the system if firmware stops servicing it.
Per-motor thermal protection (I^2t)	Continuous current-squared-time thermal model per motor. Sustained over-current accumulates thermal energy (decaying over time); exceeding the per-motor limit raises a fault and protects the winding. Live accumulator and trip limit are host-visible.
Power-rail & thermal fault monitoring	Continuous monitoring of input, motor, and logic rails for over/under-voltage and over-current, plus MCU over/under temperature, reported through a structured fault model.
Structured fault reporting	Faults aggregate into four host-readable, latching, write-1-to-clear registers ([RS] §6): Motor & I^2t (per joint); Position-sense & calibration (per joint); Power-supply (input/motor/logic/MCU); System & thermal (CPU-load, over/under-temp, watchdog-expired, unknown).
Integrity monitoring	Memory-corruption canaries, cpu workload, and stack high-water monitoring, with task-liveness checks feeding the watchdog.

14 Serviceability & Lifecycle

14.1 In-Field Firmware Update

Firmware can be updated in the field over the same MODBUS/RS-485 host link — no special programmer required. The host streams the image in chunks at its own pace and monitors progress and status registers throughout (begin → chunk → verify → commit, with abort available at any time). The complete host-side update procedure is specified in the Firmware Update Application Note [FWUP]; the firmware-update register block is defined in [RS] §16.

14.2 Verified, Rollback-Protected Installation

- Each firmware image is cryptographically verified for internal integrity and for authenticity before installation.
- The bootloader snapshots the current application before installing a new one.
- The application confirms a healthy boot; a repeatedly failing image is automatically rolled back to the previous known-good image.
- An interrupted or aborted update never corrupts the running application.

Installed vs. pending build numbers are reported to the host, so operators always know what is running and what is staged.

14.3 Reboot-Cause Reporting

The last reboot cause is reported to the host (power-on, host command, watchdog, fault, unexpected/brown-out, or firmware-update commit). Host-commanded reboot is key-protected and blocked during an active firmware update.

14.4 Non-Volatile, Host-Writable Configuration

Operational settings persist across reboots with CRC validation and automatic default-recovery. Host-writable, persistent settings include the comms-watchdog timeout, the E-stop response, and the watchdog response. The persistence framework supports forward schema migration, so settings survive firmware upgrades that change data layouts.

14.5 Demo Mode

A persistent demo mode can be enabled (via host command or console) to auto-play a scripted gesture sequence after calibration — useful for showroom, bring-up, and assessing host power.

15 Feature Summary Matrix

Feature	Customer Value	Host Exposure
6-DOF independent joint control	Dexterous, finger-level control	MODBUS read/write
Position in degrees or normalized	Integrate in whichever frame suits you	MODBUS read/write
Per-finger grip force (0–100%)	Tunable grip strength, live	MODBUS write / console
Contact detection (sensorless)	Grip feedback without a force sensor	MODBUS current readback
11 collision-safe grip poses	Ready-to-use grips, no path planning	MODBUS pose request
Custom frames & sequences	Application-specific motions	Console / NV storage
MODBUS RTU / RS-485	Standard industrial integration	Native
Multi-hand bus addressing	Many hands on one bus	MODBUS unit ID
Live position/current/grip telemetry	Full real-time visibility	MODBUS read / console
Power-rail & temperature telemetry	Health and thermal monitoring	MODBUS read / console
Session & lifetime energy/runtime	Usage and wear tracking	MODBUS read
E-stop (configurable, latched)	Safe stop on demand or fault	MODBUS command/config
Comms watchdog	Safe behavior on lost host	MODBUS config
Per-motor I^2t thermal protection	Motor protection	Automatic + MODBUS readback
Structured latching faults	No missed transient faults	MODBUS read (W1C)
Auto-calibration + PID auto-tune	Minimal setup; consistent performance	Automatic fallback from failed homing session
Handedness auto-detect	One image, either hand	N/A
In-field firmware update	Field updates over the host bus	MODBUS FW block
Signed + rollback-protected install	Safe, secure updates	Automatic
Reboot-cause reporting	Field diagnostics	MODBUS read

Feature	Customer Value	Host Exposure
Link-health diagnostics	Troubleshoot RS-485 issues	MODBUS read
NV configuration + migration	Settings survive reboot & upgrade	MODBUS

END OF DOCUMENT