VELO-X · PREDICTIVE ERROR INDUCTION SYSTEM

DOCUMENT TYPE: TECHNICAL · CLASSIFICATION: ADVANCED USER

Signal Parameters

& Tuning

VERSION	v3.2
PAGES	28
ISSUED	October 2024
DEVICE	VELO-X Gen 3 · nRF5340 · BLE 5.3

Not a medical device · Experimental use only · All risks assumed by user

Contents

01 — Architecture Overview

The Velo-X signal pipeline runs entirely on-device. No data is transmitted to external servers during normal operation. The processing chain consists of four sequential stages: acquisition, classification, decision, and actuation.

Acquisition handles raw sensor data from the EOG electrodes, PPG sensor, and 6-axis IMU. Each sensor operates on its own sampling schedule; data is timestamped and merged in the fusion buffer.

Classification applies the REM detection model to the merged buffer. The model is a lightweight decision tree trained on 14 physiological features. It outputs a REM confidence score (0–100) every 2 seconds.

Decision logic monitors the confidence score and applies the adaptive threshold algorithm to determine whether and when to issue a cue.

Actuation drives the LED driver and haptic motor. Cue parameters (intensity, pulse count, interval) are read from user configuration and applied at actuation time.

SENSOR SAMPLING SCHEDULE

SENSOR	RATE	BUFFER	NOTES
EOG (differential)	256 Hz	4 s rolling	Bandpass 0.3–40 Hz
PPG (IR + red)	64 Hz	30 s rolling	Ambient subtracted
IMU (accel + gyro)	50 Hz	8 s rolling	Low-power mode
Temp (skin contact)	1 Hz	60 s rolling	Contact detection only
Battery voltage	0.1 Hz	scalar	ADC, 12-bit

PROCESSING LATENCY BUDGET

Total pipeline latency from REM onset to first possible cue: 8–20 minutes (configurable, default 8 min). This delay is intentional — early-cycle REM windows are shallower and produce lower cue success rates.

Computational budget per 2-second window: ~4.2 ms active CPU time.
Average current draw during active processing: 1.8 mA.

02 — LED Intensity & Pulse Configuration

The LED driver operates in constant-current mode with 12-bit PWM resolution. Intensity is specified in cd/m² at the diffuser surface. Actual retinal irradiance depends on eyelid thickness and positioning — this is why auto-calibration is necessary during the first week.

The sub-threshold target is the intensity at which a cue is reliably processed by the visual cortex during REM without triggering arousal. This is individual-specific and varies by ±40% across users.

INTENSITY LEVELS (FACTORY-DEFINED STEPS)

LEVEL	CD/M²	DAC VALUE	TYPICAL USE	AROUSAL RISK
1	0.02	82	Initial calibration	Negligible
2	0.04	164	Sensitive users	Very low
3	0.08	328	Default	Low
4	0.14	573	Tolerance plateau	Moderate
5	0.22	901	High threshold users	Moderate-high
6	0.40	1638	Maximum recommended	High
7	0.80	3277	Research / override	Very high

Pulse count determines how many LED flashes occur per cue event.
Each pulse is a square wave: full intensity for the ON period, zero for OFF.

Single pulses (count=1) are harder for the dream narrative to integrate but produce fewer false wakeups. Multiple pulses increase integration probability at the cost of higher arousal risk.

The recommended default is 2 pulses. Do not exceed 4 pulses during the first 30 nights without explicit reason.

PULSE TIMING PARAMETERS

PARAMETER	DEFAULT	RANGE	NOTES
Pulse count	2	1 – 6	Per cue event
ON duration	50 ms	20 – 200 ms	LED active period
OFF duration	600 ms	300 – 1200 ms	Inter-pulse gap
Cue cooldown	8 min	4 – 30 min	Min. time between cues
Max cues/night	6	1 – 12	Safety ceiling

Pulse interval is the gap between pulses within a single cue event.
Shorter intervals (300–400 ms) tend to integrate as 'flickering' elements.
Longer intervals (800–1200 ms) may integrate as two separate events,
which can increase disorientation in the dream environment.

The default of 600 ms targets integration as a single rhythmic signal.
This is the parameter most users should not adjust.

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03 — REM Detection Pipeline

REM classification uses a 14-feature decision tree evaluated every 2 seconds. The model was trained on 847 polysomnography sessions and validated against EEG-confirmed sleep staging. On-device accuracy: 91.3% sensitivity, 88.7% specificity at the default threshold of 65.

Features are derived from all three sensor streams:

EOG FEATURES (6)

- Rapid eye movement rate (events/min)
- Eye movement amplitude (µV peak-to-peak)
- Saccade burst density (bursts/30s)
- Waveform asymmetry index
- High-frequency content ratio (12–40 Hz)
- Electrode impedance delta (Z-score)

HRV FEATURES (5)

- Mean RR interval (ms)
- RMSSD (root mean square of successive differences)
- LF/HF power ratio
- RR interval trend (slope over 5 min)
- Autonomic suppression index

MOTION FEATURES (3)

- Micro-movement count (events/min, threshold 0.02g)
- Postural stability score (rolling variance, 60s)
- Voluntary movement probability (SVM classifier output)

The confidence score is computed as a weighted sum of tree node outputs, normalized to 0–100. A score above the detection threshold triggers the REM-active state. The device remains in REM-active until the score drops below the threshold for 3 consecutive windows (6 seconds).

False positives (non-REM classified as REM) are more costly than false negatives: a misclassified cue during NREM or light sleep carries high arousal risk. The default threshold of 65 is conservative for this reason.

Advanced users who have established a strong baseline and tolerate higher sensitivity can lower the threshold to 55. Do not go below 50.

Threshold selection guidelines:

If you consistently wake during cues: raise threshold by 5 points.
If app logs show few REM-active windows: lower threshold by 3 points.
If cue integration rate is high but lucid events are rare: the detection
is likely correct — the issue is recognition, not timing.

The threshold should be adjusted in single steps, with at least 5 nights
of data between each change. Do not make multiple adjustments simultaneously.

04 — Adaptive Threshold Algorithm

The adaptive algorithm adjusts cue intensity based on physiological response to previous cues. It operates on a 7-night rolling window and updates once per night after the session ends.

The core loop:

1. Issue cue at current intensity level.
2. Monitor post-cue window (90 seconds) for response indicators.
3. Classify response as: arousal / integration / null.
4. Update intensity estimate using exponential moving average.
5. Apply intensity at next cue opportunity.

RESPONSE CLASSIFICATION CRITERIA

CLASS	CRITERIA	ACTION
Arousal	HRV drops >15%, motion events >2, EOG shows waking pattern	Decrease intensity -1 step
Integration	EOG change, no arousal markers, HRV stable	Maintain or increase +1
Null	No detectable physiological response	Increase +1 step if 3x null

The algorithm converges to a stable intensity within 14–21 nights for most users. Once converged, it makes smaller adjustments (+/-0.5 step) to track slow drift from factors like sleep position changes, weight shifts, or seasonal variation in sleep architecture.

Manual override: the adaptive algorithm can be suspended in the app. Use this when introducing a deliberate change (new sleeping position, new bed, travel) that would otherwise confuse the algorithm for several nights. Resume adaptive mode after the change has stabilized.

Algorithm parameters exposed in advanced settings:

- learning_rate: controls EMA weight for new observations (default 0.2)
- arousal_weight: penalty multiplier for arousal events (default 2.0)
- null_patience: consecutive nulls before intensity increase (default 3)
- max_delta_per_night: maximum intensity steps change per session (default 1)

These parameters are stable across most users. Adjust only if you have specific reasons and understand the tradeoffs. Higher learning_rate produces faster adaptation but more instability.

05 — HRV Integration

Heart rate variability serves two functions in the pipeline: sleep depth estimation and post-cue arousal detection.

For sleep depth, the device monitors the LF/HF ratio (low-frequency to high-frequency power). Lower LF/HF indicates higher parasympathetic tone, which correlates with deeper, more stable REM. Cues issued during high-LF/HF windows have lower integration success rates and higher arousal risk.

The HRV gate blocks cue issuance when LF/HF exceeds 2.5 (default). This prevents cues during transitional sleep phases even when the EOG classifier reports REM-active.

RMSSD is the primary metric for beat-to-beat variation. Values below 20 ms during REM may indicate stress or incomplete sleep pressure recovery. The device logs RMSSD for each session. Tracking this over weeks reveals patterns: lower RMSSD nights tend to produce fewer integration events.

Practical guidance: if your RMSSD trend is declining over multiple nights, the protocol is likely adding load. Consider reducing cue frequency or taking a 5-night pause before the pattern becomes entrenched.

The PPG sensor accuracy is sufficient for trend monitoring but not for clinical HRV assessment. Do not use device HRV readings for health decisions.

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06 — Motion Artifact Filtering

Motion artifacts contaminate both EOG and PPG signals. The IMU provides a reference channel for artifact subtraction using adaptive LMS filtering.

Two classes of motion are distinguished:

Micro-movements: sub-threshold shifts during active sleep. These are expected in REM and are included in the feature set.

Macro-movements: repositioning, partial arousals, voluntary shifts. These trigger a 45-second blanking window during which no cues are issued and the REM classifier output is flagged as unreliable.

Side-sleeping users experience different artifact profiles than back-sleepers. The IMU-to-EOG correlation is lower in side-sleeping positions because head rotation is decoupled from eye movement. This is handled by a position-aware calibration mode that activates during the first 20 minutes of each session.

If motion artifact quality score is consistently below 60 (visible in app):

1. Check strap tension — should be snug, not tight
2. Reposition EOG contacts — should rest flat against the orbital bone
3. Run strap fit diagnostic before sleep for 3 consecutive nights
4. If score remains low, contact hardware support (rma@velo-x.dev)

07 — Timing Windows

Timing windows define when in the sleep cycle cues can be issued.
Three independent window parameters control the temporal envelope:

  onset_delay: minimum time from REM onset to first possible cue (default 8 min)
  session_start: earliest time after sleep onset to enable the system (default 90 min)
  session_end: latest time before planned wake to allow cues (default 60 min)

The session_start parameter ensures the first full sleep cycle completes
before any intervention. Early REM windows are typically shorter and less
stable — poor targets for induction. Disabling this guard increases false
positives substantially.

RECOMMENDED WINDOW CONFIGURATIONS

USE CASE	ONSET_DELAY	SESS_START	NOTES
Default	8 min	90 min	Most users, first 30 nights
WBTB supplement	4 min	20 min	After re-entry from WBTB wake
Short sleep window	6 min	60 min	Less than 6h available
High-arousal user	12 min	120 min	Fragmentation history
Advanced / trained	4 min	60 min	Post-30 nights, stable baseline

08 — Advanced Configuration

Advanced configuration is accessible after Night 30, when the baseline model is considered stable. These settings are not exposed in the default app interface — access via Settings > Developer > Signal Config.

All advanced parameters are reset on factory reset. Export your configuration before applying a firmware update.

ADVANCED PARAMETER LIST

PARAMETER	DEFAULT	RANGE	DESCRIPTION
rem_confidence_threshold	65	50–85	REM classifier cutoff
hrv_gate_lf_hf_max	2.5	1.5–4.0	HRV gate threshold
intensity_learning_rate	0.20	0.05–0.5	Adaptive EMA weight
arousal_penalty_weight	2.0	1.0–4.0	Arousal response weight
null_patience	3	1–6	Nulls before intensity++
max_delta_per_night	1	0–3	Max intensity steps/night
motion_blank_duration_s	45	20–120	Post-movement blank
session_start_min	90	20–180	Earliest cue time
session_end_min	60	0–180	Buffer before wake
max_cues_per_night	6	1–12	Safety ceiling

Configuration profiles can be saved and named in the app. Useful for comparing protocols systematically over multi-week periods.

When sharing configuration profiles on The Latent Space, always include your night count, baseline signal quality score, and sleep window. A profile that works for Night 60 user with 8-hour windows will not transfer cleanly to Night 15 with a 6-hour window.

There is no universal advanced configuration. The parameters are exposed because experienced users have legitimate reasons to adjust them, not because adjusting them is the path to better results.

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09 — Troubleshooting Signal Issues

High impedance on one or both EOG contacts

Clean contact area with mild alcohol solution. Allow skin to dry completely.
Reposition strap so contacts rest on the flat orbital bone surface.
If impedance remains above 10 kΩ, check cable continuity and contact
pad condition. Replace contact pads if worn (available as spare part SP-02).

REM windows not detected despite apparent dream sleep

Lower rem_confidence_threshold by 5 points. Verify strap tension.
Check motion artifact score — if below 60, address artifact issues first.
Some users have naturally low-amplitude EOG during REM. If signal amplitude
is consistently below 12 µV, contact support for custom calibration.

Cues triggering consistent waking

Reduce intensity level by 2 steps. Increase onset_delay by 4 minutes.
Verify session_start is not catching early sleep cycles.
Some users are highly sensitive to light during sleep. Try intensity level 1.

App shows high REM classification but no cues issued

Check timing window settings. Confirm session_start and session_end are not
blocking the available REM window. Verify max_cues_per_night has not been
reached. Check HRV gate — high LF/HF may be blocking cue issuance.

WHEN TO CONTACT HARDWARE SUPPORT

Signal issues that persist after 14 days of troubleshooting, impedance consistently above 12 kΩ after contact replacement, any visible damage to electrodes or cable. Email: rma@velo-x.dev with device serial number and export of the last 14-night session log.

10 — Firmware Parameter Reference

Parameters are stored in non-volatile memory (NVS) on the nRF5340.
They persist across power cycles and firmware updates unless explicitly reset.
BLE characteristic UUIDs for direct parameter access are documented in
Hardware Specifications (v3.2.1, Appendix C).

NVS PARAMETER NAMESPACES

velox/signal	Signal processing parameters (threshold, intensity, timing)
velox/adapt	Adaptive algorithm state (intensity history, session counts)
velox/user	User identity (device serial, pairing keys)
velox/session	Last session data (used for app sync)
velox/hw	Hardware calibration (factory-set, do not modify)

Firmware v3.2 changelog (since v3.1.4):

- Improved REM classifier accuracy (+3.1% sensitivity on held-out set)
- Fixed HRV gate edge case where LF/HF computation drifted after 4h sessions
- Added motion artifact score to BLE session report characteristic
- Reduced average current draw by 0.3 mA through IMU duty cycle optimization
- Corrected pulse timing jitter from 12 ms to 2 ms (max)
- Added max_cues_per_night parameter (previously hardcoded at 8)

Known issues in v3.2:

- Calibration data occasionally corrupted after factory reset + immediate re-pair
  Workaround: wait 30 seconds after factory reset before pairing
- LF/HF ratio display in app shows 10x actual value (display bug, not sensor bug)
  Fixed in v3.2.1 (pending release)

Appendix — Full Parameter Index

All configurable parameters in alphabetical order.

PARAMETER	DEFAULT	RANGE	SECTION
arousal_penalty_weight	2.0	1.0–4.0	04
intensity_learning_rate	0.20	0.05–0.5	04
led_intensity_level	3	1–7	02
max_cues_per_night	6	1–12	08
max_delta_per_night	1	0–3	04
motion_blank_duration_s	45	20–120	06
null_patience	3	1–6	04
onset_delay_min	8	4–30	07
pulse_count	2	1–6	02
pulse_off_duration_ms	600	300–1200	02
pulse_on_duration_ms	50	20–200	02
rem_confidence_threshold	65	50–85	03
session_end_min	60	0–180	07
session_start_min	90	20–180	07
hrv_gate_lf_hf_max	2.5	1.5–4.0	05