ADAPTIVE AI DOG LEASH

Prototype Build Specification & Construction Guide

Practical engineering document for building a working motorized, sensor-driven, progressively calibrating retractable leash prototype.

Concept reference – motorized reel, load path, OLED, geared drive

Version 0.9 • July 2026 • Build-focused technical document

1. Prototype Goals

The first working prototype must demonstrate closed-loop control of leash length and resistance in response to measured tension and extension velocity. It does not need polished industrial design or final battery life. Core proof points:

- Detect rising tension early and apply graded motor resistance before full extension.
- Actively shorten the leash when the dog forges ahead under load.
- Lengthen or reduce resistance when tension drops and the dog returns to position.
- Provide a clear manual override lock that is always available.
- Stay within safe force limits for a medium dog (target class: 25–55 lb).
- Log basic session data (tension peaks, pull events) for later analysis.

2. System Block Diagram (Logical)

Handle (human side) contains: motor + gear reduction + reel + clutch, load cell in the force path, rotary encoder on reel shaft, IMU, microcontroller, battery, OLED, buttons, and brake/lock mechanism. Optional collar-side accelerometer communicates via BLE for relative motion. Control loop runs on-device at 50–100 Hz.

Primary sensing path: Load Cell → HX711 (or equivalent) → MCU. Length/velocity path: Encoder → MCU. Actuation path: MCU → Motor Driver → Geared Motor → Clutch → Reel.

3. Mechanical Subsystem

3.1 Core Requirements

• Continuous torque capability under load sufficient to resist a medium dog’s pull without stalling (target continuous ~1.5–3 Nm at the reel after gearing, subject to testing).
• Mechanical clutch or slip mechanism so the motor cannot apply dangerous force if the control loop fails.
• Manual brake/lock that physically prevents reel rotation independent of electronics.
• Low-stretch line or flat tape, 4–5 m usable length for first prototype.
• Housing that can be 3D-printed or fabricated from existing retractable leash shells for Phase 0.

3.2 Recommended Starting Approach (Phase 0)

Do not design a full custom housing first. Take a robust existing retractable leash (Flexi-style or similar with accessible reel), remove or disable the spring if necessary, and adapt the reel shaft to accept a geared motor + encoder. Mount a small inline load cell or strain-gauge assembly in the line path or on the handle force transfer. This gets a functional closed-loop system running weeks faster than a clean-sheet design.

3.3 Critical Mechanical Details

- Gear reduction: high enough for torque, low enough for acceptable retraction speed (planetary or multi-stage preferred).
- Clutch: friction or magnetic slip set below injury threshold; must be testable and adjustable.
- Line guide / anti-tangle: maintain clean spooling under powered retract and free payout.
- Handle ergonomics: one-handed operation of lock button while walking is mandatory.
- Fail-safe: on power loss the reel must free-spool or spring-assist retract — never remain locked by electronics alone.

4. Electronics & Sensing

4.1 Minimum Viable Sensor Set

Sensor	Purpose	Notes
Load cell + HX711	Tension (force)	Inline or handle-mounted; 5–20 kg range typical
Rotary encoder	Length + velocity	Magnetic or optical on reel shaft
IMU (6-axis)	Handler motion	Detect stops, direction changes
Optional collar accel	Dog relative motion	BLE; not required for first closed-loop proof

4.2 Compute & Drive

• MCU: ESP32-S3 (or ESP32) preferred for built-in BLE/Wi-Fi, sufficient GPIO, and easy Arduino/PlatformIO tooling.
• Motor driver: capable of bidirectional control with current sensing (e.g., DRV8871, BTS7960, or equivalent brushed; or FOC driver if using BLDC).
• Power: 2S or 3S Li-ion / LiPo with protection; USB-C charging preferred. Size for at least 45–60 min continuous walking load.
• Display: small OLED (0.96" or 1.3") for live tension, mode, and status.
• User inputs: mode button(s), lock switch, optional potentiometer for sensitivity during early testing.

4.3 Preliminary BOM (Phase 0–1)

Item	Example / Notes	Approx
Geared DC motor + encoder	High reduction planetary, 12–24 V class	$25–60
Motor driver	Current-sensing H-bridge	$8–25
Load cell + amp	5–20 kg + HX711	$8–15
MCU board	ESP32-S3 DevKit or equivalent	$5–12
OLED + buttons	0.96–1.3" SSD1306 class	$4–8
Battery + protection	2S/3S pack + BMS / charge board	$15–35
Mechanical base	Donor retractable + custom mounts / clutch	$20–50
Misc (wire, fasteners, 3D print)	—	$15–30

Phase 0 parts cost target: under $150–200 excluding tools and printer filament.

5. Control Logic (First Implementation)

Start simple. Do not begin with full adaptive ML. Implement a transparent, tunable state machine first.

5.1 Core Loop (pseudocode outline)

```
read tension, length, velocity
if manual_lock active → hold position / brake
else if mode == HEEL → target short length band; increase resistance on rising tension
else if mode == LOOSE → maintain light tension band; shorten on sustained high force
else if mode == FREE → soft limits only
apply motor command (torque or position setpoint) within safe current limits
update OLED + log peak events
```

5.2 Progressive Calibration (Phase 2)

Once basic closed-loop works reliably, add a simple adaptive layer: track average peak tension and pull frequency per session. Slowly lower the allowed tension threshold or shorten the “good” length window across sessions according to a configurable schedule. Keep the adaptation visible and overridable by the user.

6. Safety Requirements (Non-Negotiable)

Any motorized leash can injure a dog or handler if force limits or fail-safes are inadequate. Treat the following as hard requirements before any live animal testing:

• Hard mechanical torque / force limit sized for the target dog weight class.
• Motor current limit and thermal protection in firmware and preferably in hardware.
• Power-loss behavior: free-spool or spring retract — electronics must not leave the reel locked.
• Manual mechanical lock/brake that works with zero power.
• No electrical stimulation of the animal in the base design.
• Clear labeling of maximum recommended dog weight.
• Static and dynamic pull tests on a fixture before any dog is attached.

Do not attach a dog until force limits, clutch behavior, and power-loss response have been measured and documented.

7. Build Phases

Phase 0 – Bench Proof (1–3 weeks)

Goal: closed-loop tension → motor response on a fixed test stand.
Actions: adapt donor reel, mount motor + encoder + load cell, implement basic threshold control, verify force limiting and power-loss behavior on a fixture. No dog yet.

Phase 1 – Walking Prototype (2–5 weeks)

Goal: usable one-handed device that can be walked with a calm, trained dog under controlled conditions.
Actions: integrate battery, OLED, mode selection, improve packaging, add logging, perform supervised outdoor tests with known low-pull dogs first. Iterate clutch and control gains.

Phase 2 – Adaptive Layer + Robustness

Goal: progressive calibration works and the device survives repeated real walks.
Actions: implement session-based adaptation, improve mechanical durability, refine thermal and battery behavior, expand to a wider range of dog sizes and pull strengths under controlled protocols.

Phase 3 – Productization Path

Custom housing, multiple size classes, refined motor selection, certification path, companion app, IP filings, and manufacturing readiness. Only after Phase 1–2 prove the core value.

8. Minimum Test Protocol Before Live Use

1. Static force test: measure maximum force the system will apply or resist under lock and under motor command.
2. Dynamic pull test: sudden high-force pulls on a fixture; confirm clutch slips and electronics limit current.
3. Power-loss test: remove power under load; confirm free-spool or safe retract.
4. Thermal test: continuous operation at expected walking load; confirm no overheating of motor or driver.
5. Manual override test: lock engages cleanly with one hand while under moderate tension.
6. Only then: supervised walks with a calm, known dog, short sessions, immediate stop capability.

9. Key Technical Risks

Risk	Mitigation
Insufficient torque or excessive current draw	Oversize motor early; measure real pull forces; add current limiting
Line tangle / poor spooling under power	Careful guide geometry; test retract under side loads
Clutch too stiff or too loose	Adjustable friction design; empirical tuning per weight class
Latency in tension response	Fast load-cell sampling; simple predictive shortening on rising edge
Handler loses control / entanglement	Strong manual lock, wrist strap option, clear emergency procedure
Battery / thermal failure mid-walk	Conservative sizing, thermal cutback, graceful degradation to free-spool

10. Immediate Next Actions

1. Select a donor retractable leash with accessible reel and robust housing.
2. Choose motor + gear + encoder combination and order load cell + HX711.
3. Design simple 3D-printed or laser-cut mounts for motor and load path.
4. Implement basic Arduino/PlatformIO sketch: read load cell + encoder, drive motor with current limit.
5. Build a fixed test stand and characterize force vs. motor command and clutch slip point.
6. Document every force measurement before any animal contact.

This document is a build specification for prototype development only. All force limits, clutch settings, and safety behaviors must be empirically validated. Never use an untested motorized leash with a dog.
July 2026 • Adaptive AI Dog Leash Prototype Build Spec v0.9