Concept Proposal: Mini Morphobot-Inspired Mobility Platform

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1 Part I: Concept Overview

1.1 Goal and Vision

Our team will build a laptop-scale "Mini Morphobot" that emulates the appendage repurposing strategy of Caltech's Multi-Modal Mobility Morphobot (M4) to unlock multiple locomotion modes within a single compact robot.[1] The overarching goal is to demonstrate that a small number of carefully designed hybrid appendages can deliver wheeled cruising, crouched crawling, and self-righting without swapping hardware. Achieving convincing transformations inside one term would validate the feasibility of morphologically plastic field robots that can respond to collapsed infrastructure, lab accidents, or remote inspections without relying on entirely different platforms for each environment.

1.2 Form Factor and Operating Concept

The final product will be a 30 cm $\times$ 25 cm carbon and nylon chassis carrying four identical appendage pods arranged in an "X" configuration. Each pod combines a back-driven shoulder servo, a 3D-printed four-bar linkage, and a 70 mm wheel that can swivel outward to roll or fold inward to act as a padded foot. In high-clearance mode the appendages lift the body to step over 12 cm debris; in scouting mode the same wheels tuck under the belly to create a stable, low-profile crawler stance; and in recovery mode opposing pods swing over the center of mass to act as reaction arms for self-righting or short hops. Swapping between modes takes under 8 seconds and is triggered through a tablet interface to showcase how a small-scale morphobot can continuously adapt while operators stay at a safe standoff distance.

1.3 Conceptual Interest and Motivation

The interesting element is the explicit reuse of appendages across contrasting tasks, mirroring how M4 leverages the same hardware to fly, roll, and tumble. Instead of brute-force redundancy (i.e., adding distinct legs, tracks, and manipulators), the Mini Morphobot aims to prove that careful kinematic packaging, compliant locking mechanisms, and software-defined behaviors can stretch a limited actuation budget. This approach makes the project worth pursuing because it bridges cutting-edge research and practical constraints: if successful, first responders or facilities teams could deploy a single carry-on robot that morphs to fit elevators, stairwells, or ventilation ducts without being mechanically reconfigured by hand.

[1] E. Sabree et al., "Multi-Modal Mobility Morphobot (M4) with appendage repurposing for locomotion plasticity enhancement," *Nature Communications*, 2023.

1.4 Functional Components

FC1: **Morphing Chassis and Appendage Hubs** — Lightweight central frame with indexed mounting plates, detents, and wiring passthroughs that keep the appendages rigid in all three targeted poses while enabling quick service access.

FC2: **Transformable Appendage Module** — Shoulder servo, compliant four-bar linkage, and passive magnetic lock that rotate each wheel pod between "drive," "crawl," and "reaction arm" positions without backlash.

FC3: **Hybrid Drivetrain** — Dual-wheel pods with rubber tires and integrated micro-spiked paddles, each powered by a compact gearmotor so the same hardware can provide smooth rolling or high-traction bracing at low speeds.

FC4: **Perception and State Sensing** — IMU, wheel encoders, two time-of-flight range sensors, and limit switches to detect when appendages are fully locked, all fused onboard for pose estimation and safety interlocks.

FC5: **Supervisory Control and Autonomy Stack** — Teensy 4.1 microcontroller linked to a Jetson Nano companion computer running ROS 2 nodes for gait scheduling, teleoperation, semi-autonomous stance planning, and data logging.

FC6: **Power and Communications Backbone** — 4S Li-ion battery pack, buck regulators, electronic fuses, and a Wi-Fi module that distribute power safely, report current draw, and maintain a robust command link in cluttered indoor spaces.

2 Part II: Responses to Concept Questions

1. What is the value of your product to the end-user? The end-user is a first responder or facilities engineer who needs rapid situational awareness in constrained, debris-filled environments. The Mini Morphobot lets them drive quickly down hallways, then crouch to squeeze under shelving, and finally brace itself to climb over a blocked doorway without manually swapping tools. Delivering three locomotion modes from one carry-on robot reduces the amount of gear they tote and shortens the time between detection of a hazard and the first safe inspection pass, providing operational value that is both practical (fewer payloads) and emotional (confidence that one robot can adapt in the field).

2. What is the closest alternative to your product? The closest alternative is pairing a Boston Dynamics Spot (for legged traversal) with a treaded inspection robot such as the FLIR FirstLook. Those platforms share individual capabilities with our concept, but they rely on dedicated appendages for each task, weigh far more, and cost orders of magnitude more than a student-built morphobot. The Mini Morphobot trades raw payload and autonomous navigation depth for morphing efficiency: the same appendages roll smoothly like Spot's wheels-in-feet, lock rigidly to brace like a micro-limbed crawler, and swing to act as a tail for balance, making the unit nimble enough to deploy inside cramped labs without specialized launch equipment.

3. What is the metric of success for your product? Success will be measured by mode coverage and traversal performance: the robot must (i) transition between drive, crouch, and recovery configurations in under 8 seconds, (ii) maintain at least 0.6 m/s average speed in drive mode on flat terrain, and (iii) surmount a 12 cm obstacle in crawl stance while keeping all electronics fully enclosed. Each criterion is quantifiable with timing scripts, encoder-based velocity estimation, and motion-capture verified obstacle trials, so progress can be tracked objectively throughout the term.

4. Which aspect will be developed to a polished finished product? We will polish the mechanical morphing subsystem. A finished state means the appendage linkages latch crisply with no rattling, the wheel pods align repeatably (within 1°) during every transformation, and the exposed surfaces are enclosed with laser-cut covers so the robot looks intentional rather than prototype-grade. Negatively, a rough finish would show visible flex, require hand nudging to complete transformations, or allow cables to snag; those outcomes are specifically what the polished design will avoid through tuned detents, printed guides, and cable routing grommets.

5. Which aspect(s) will you not develop to a finished product? Autonomous perception and global navigation will stay at a proof-of-concept level. We will leverage ROS teleoperation and basic waypoint scripts for demos, but we do not plan to harden indoor SLAM, obstacle classification, or long-duration mission autonomy. These software stacks would demand far more testing than the schedule allows, so we will treat them as scaffolding that enables live evaluations rather than production-ready features.

6. What is your most critical module and why? The Transformable Appendage Module (FC2) is the most critical because it concentrates the highest mechanical risk and determines whether the robot can actually repurpose its limbs the way M4 does. It combines high torque requirements, repeated impacts, and precise alignment tolerances; if it underperforms, every locomotion mode degrades simultaneously. Consequently, we will front-load prototyping time, build an instrumented test jig, and iterate until the module can sustain 500 consecutive morph cycles without misalignment.

7. What kind of data infrastructure will you need and how will you test it? Our data infrastructure will stream encoder ticks, IMU orientation, power telemetry, and joint-state flags over ROS 2 topics, log them to a PostgreSQL-backed bagging node, and expose a lightweight dashboard for TAs to review trials. We will mock the data using a Python simulator that replays recorded gait profiles while injecting latency and packet drops, then run hardware-in-the-loop tests where the Teensy publishes synthetic sensor packets into the Jetson pipeline. Verification will focus on proving that every transformation command is accompanied by synchronized telemetry, making it straightforward to diagnose failures during demos.