Sensor Package for Internal Detection in Extraterrestrial Regions

Low-power distributed nodes for early detection, localization, and reporting of internal habitat anomalies.

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PROBLEM & OBJECTIVE

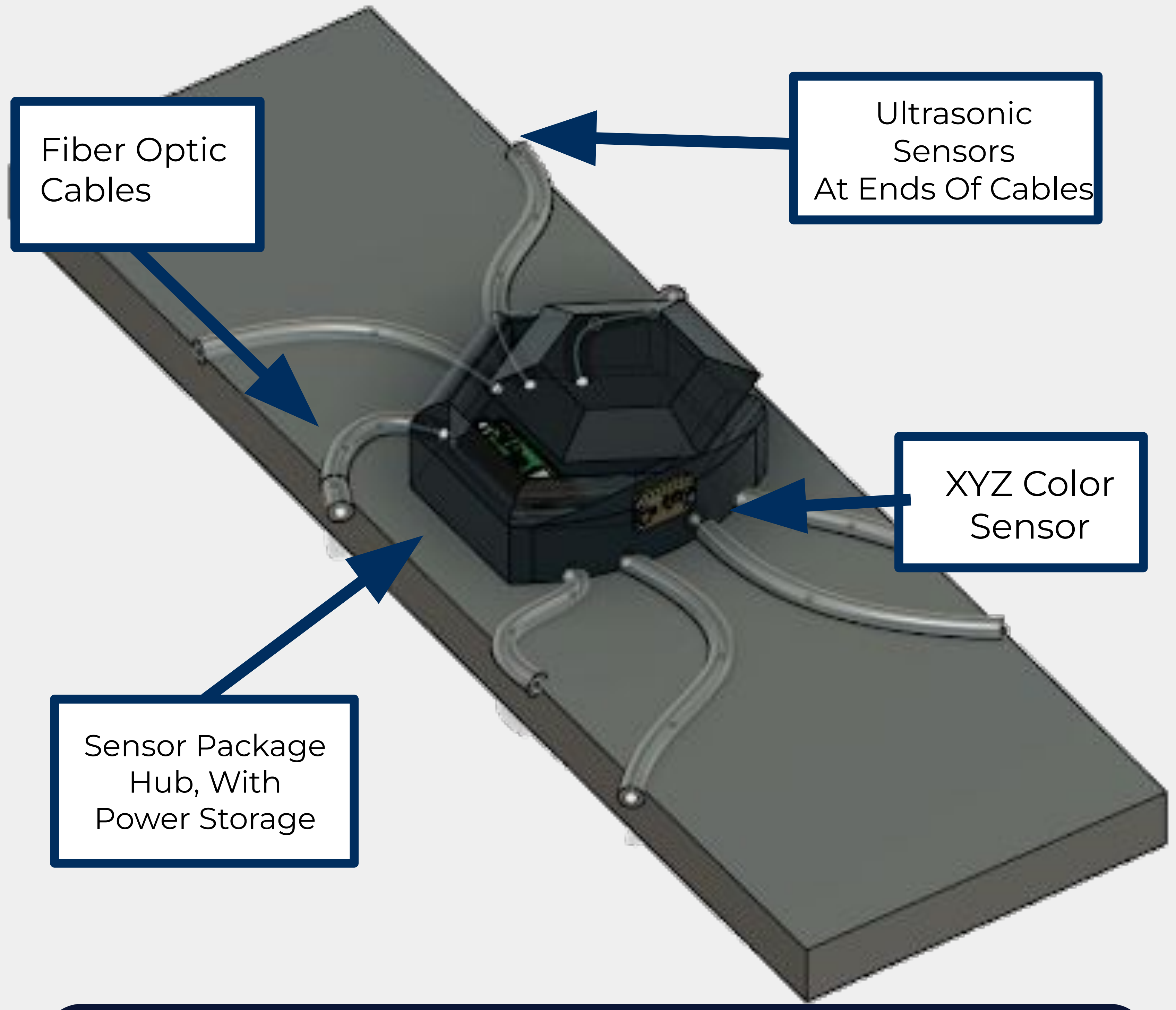
Habitats need clear structural health monitoring without added complexity, power draw, or crew workload.

SPIDER achieves this goal by integrating several structural health monitoring necessities with very few sensors. SPIDER uses ultrasonic sensors and piezoelectric wafers to detect local structural health events, such as impact, overheating, leaks, or panel damage. Using this in combination with Fiber Bragg Grating optical cables (FBGs), it can report the location and severity of these hazards as well as tiny changes in strain, to report hazards early on with confidence. The use of these cables allows it to cover a predicted 50 square meters of habitat wall. SPIDER additionally incorporates a colorimetric sensor, which is used in conjunction with hazard-reactive paint, allowing it to identify multiple health hazards to the crew in a single integrated package. SPIDER is concurrently capable of harvesting its own power passively with photovoltaic cells and a thermoelectric generator, reducing the need for complex maintenance and power.

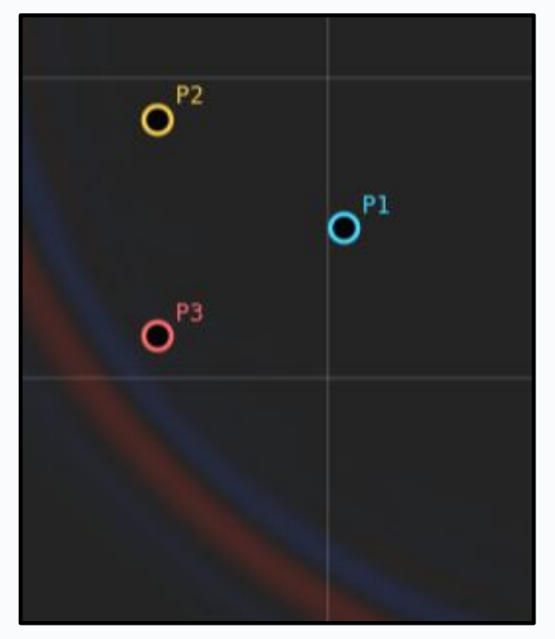
TRL 4
Current prototype level

6–8 yr
Current adoption window (to TRL 9)

149 grams, 3” width
Weight and size per sensor node

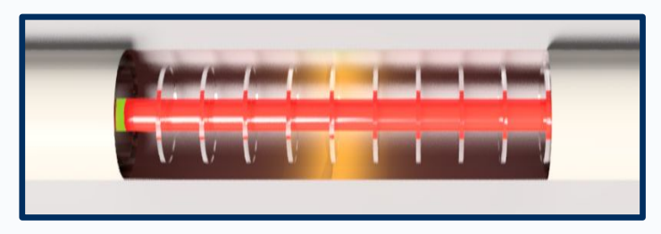


SUBSYSTEMS



Piezoelectrics/ultrasonics

Piezoelectrics and ultrasonics work together to localize impacts and structural defects before they become critical.



Fiber Bragg Grating (FBG)

FBG cables can identify small changes in strain and temperature over a large surface area, such as habitat walls.

Colorimetric sensing

Colorimetric sensing uses a single sensor to report crew health hazards, as colorimetric paint fluoresces when exposed to specific hazards.

VERIFICATION & VALIDATION

All subsystems were tested independently with their own pass/fail criteria, all subsystems passed initial testing.

Subsystem	Test	Pass Criterion
Piezoelectrics	Controlled impacts on an acrylic sheet with sensors mounted	location error ≤ 5cm
Power	Power harvesting capabilities of thermoelectric generator and photovoltaic cells	Energy harvest ≥ 25mw avg
Colorimetrics	Color changing paint fluoresces under a heat hazard (various temps)	A reliable alert after a color change 30-40°C (over many cycles of use)
Optical cables	Calibration of the cable in a cantilever orientation	Consistent linear regression performance

Budget

Projected cost of implementation : $4,081,000

EXPERIMENTAL RESULTS

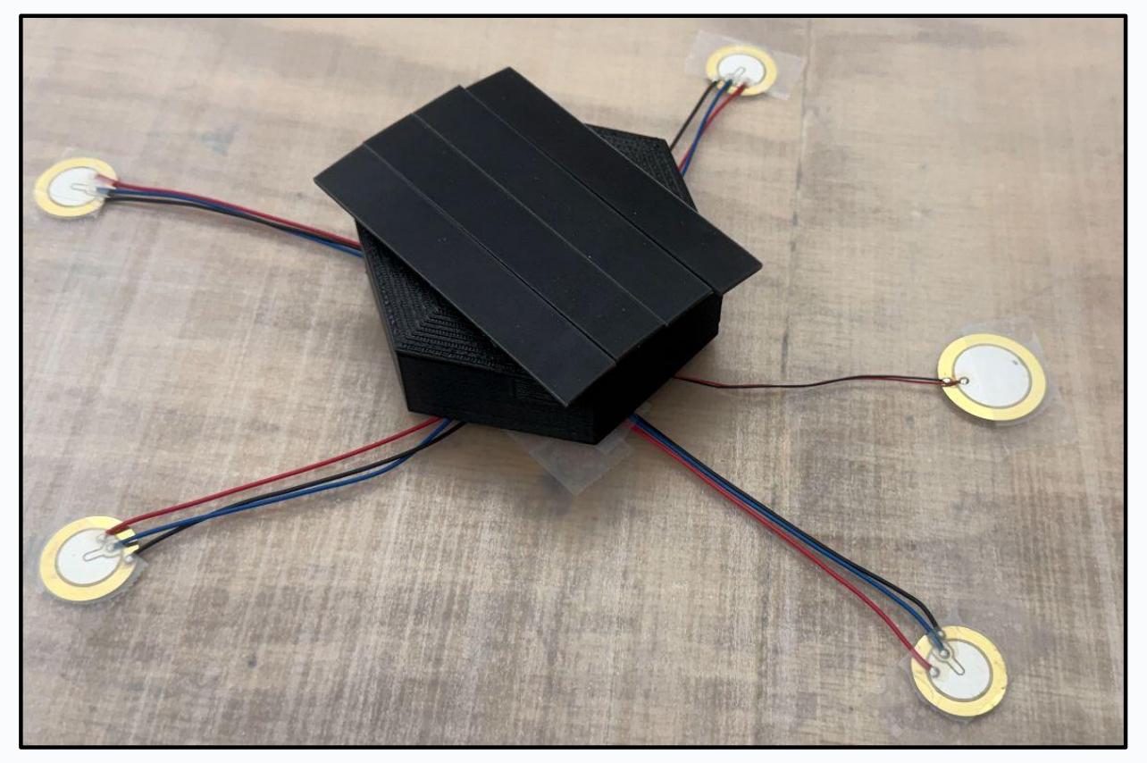
All systems tested in isolation; further testing involves complete integration of subsystems into a single dedicated hub.

Piezoelectrics
3.4cm impact localization error at 42.5cm

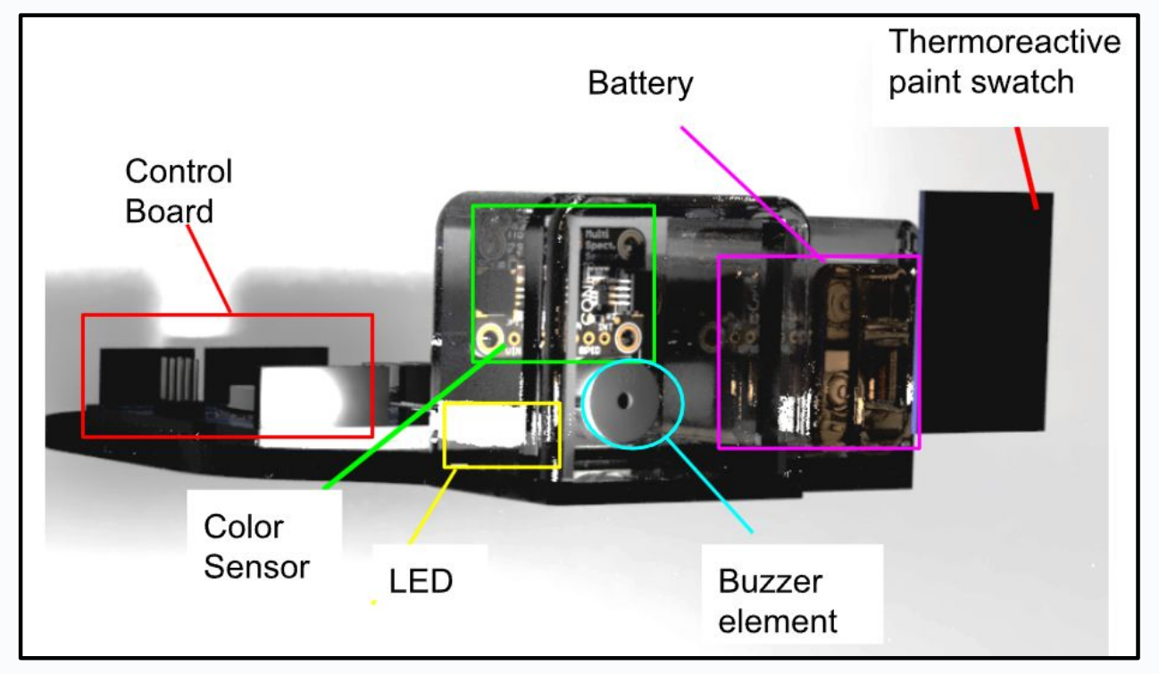
Colorimetrics
Successful detection rate at 0.5-9s ranging 30°-40°

Energy Harvested
32.1mW average energy harvest in

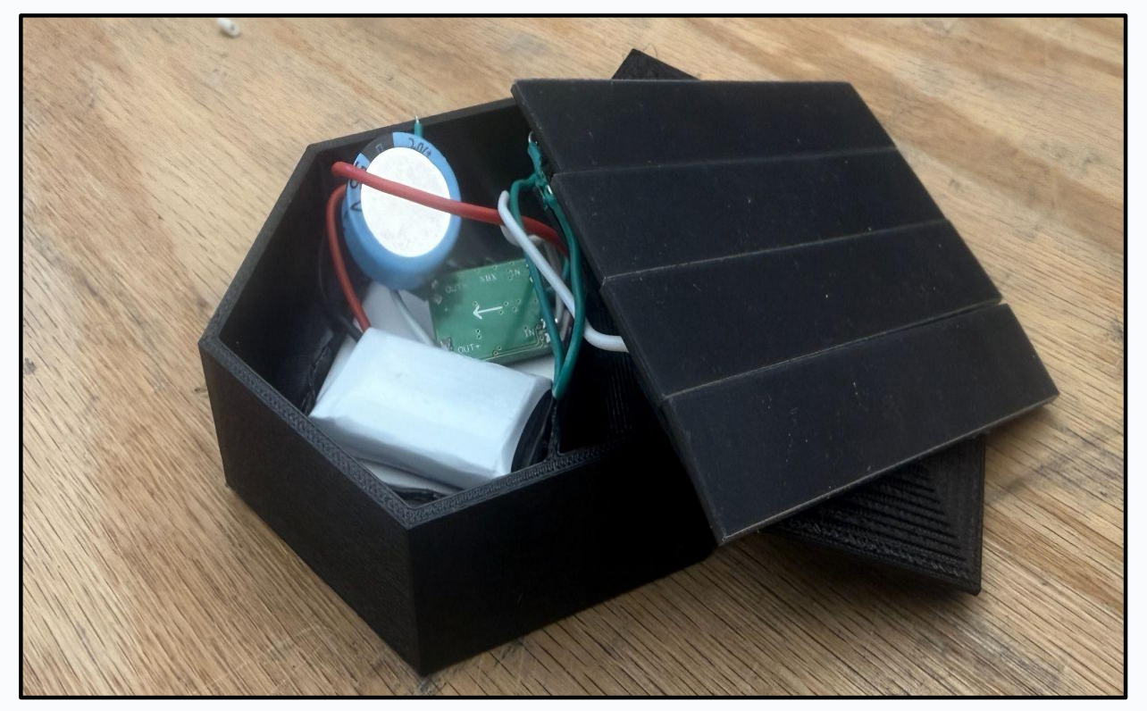
Fiber Bragg Gratings
Exhibited linear regression



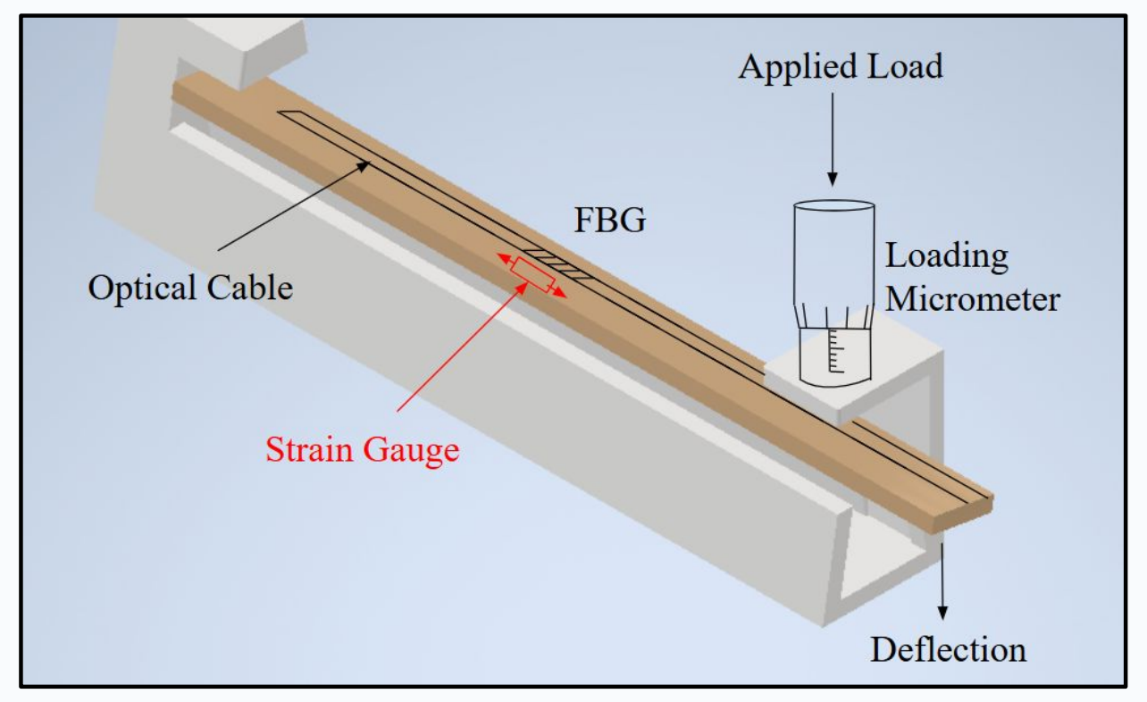
Piezoelectric testbed, with wafers mounted to an acrylic sheet.



Colorimetric testbed, with thermoreactive paint.



Power harvesting test setup, with photovoltaic cells and thermoelectric generator.



Fiber Bragg Grating optical cable testbed, with cantilever orientation.

MISSION IMPACT & PATH FORWARD

SPIDER will be verified through repeated testing of hazard detection sensitivity, response time, sensor reliability, and subsystem integration. Since SPIDER is designed for a climate-controlled lunar habitat, testing will be conducted in air-conditioned laboratory conditions under Earth atmosphere. After subsystem validation, all three sensing systems will be tested together to confirm coordinated hazard detection and stable operation. Acceptance will require successful hazard detection within defined sensitivity and response thresholds during continuous operation. Key risks include sensor integration complexity, limited detection sensitivity, and prototype schedule constraints, which will be mitigated through modular testing, early integration, and iterative refinement.

Phase	Year	TRL	Goal	Key Activities	Exit Criteria
Post-HuLC Baseline	0	TRL 4	Component validation in lab	Integrated prototype; initial calibration; baseline hazard demos	Lab-validated SPIDER prototype
Phase 1 – Environment Validation	0–1	TRL 4 → 5	Validate integrated habitat-like system	Gen-2 prototype; test color, ultrasonic, and fiber optic sensors	Repeatable hazard detection in relevant environment
Phase 2 – Prototype Demonstration	1–2	TRL 5 → 6	Demonstrate in high-fidelity habitat analog	Gen-3 prototype; habitat simulators; long-duration reliability	Documented habitat analog performance
Phase 3 – Operational Prototype	2–4	TRL 6 → 7	Deployment-like system in operational environment	Environment-like hardware; EMI/EMC, vibration, dust ingress, handling tests	Operational demo and verification reports
Phase 4 – Qualification	4–6	TRL 7 → 8	Qualify final design	Build qualification and flight units; thermal-vac, vibration, shock; finalize interfaces	Qualification testing complete; readiness reviews
Phase 5 – Full Implementation	6–8	TRL 8 → 9	Demonstrate in space environment	Deploy in lunar habitat; monitor hazards during mission	Successful mission operation and performance verification