Sensor Package for Internal Detection In Extraterrestrial Regions (SPIDER)

New Mexico Institute of Mining and Technology

HULC HUMAN LANDER CHALLENGE

OBJECTIVE

Develop a wall-mounted sensor package to reduce weight and improve sensitivity of lunar base structural health monitoring systems

Technical Approach

- Design a prototype sensor housing node containing multiple sensing modalities
- Develop signal processing hardware and algorithms to identify critical structural or environmental damage
- Validate health monitoring capabilities through simulation and experimentation

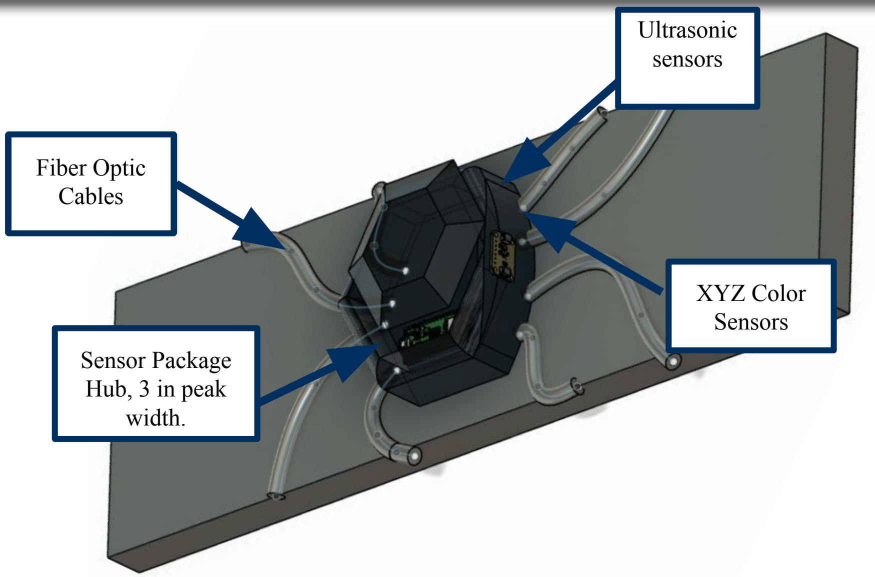

Fig 2: Prototype SPIDER Hub

Key Design Details & Innovations of the Concept

Innovation: reduced-size wall sensing nodes, cross-validated through 3 modalities to detect radiation, temperature, and structural damage

Bio-inspired design

Sensing design inspired by spider in a web

Ultrasonic

Sensing vibrations on thin wires across lunar wall substrate

Colorimetric paint

Radiochromic/thermochromic color sensing

FBGs

Web of dispersed optical cables

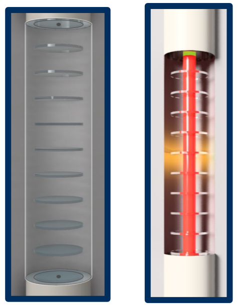

Fig 1: Fiber-Bragg Grating Sensor

	3/4/2026	NMIMT Human Lander Challenge			
	Allocations				
	Source(s)	Amount			
1	HulC Second Phase Funds	$ 9,000			
	Total Allocation:	$ 9,000			
	Expenditures				
	Description	Budgeted	Spent to date	emaining to sper	Over/Under
1	Piezoelectrics	$1,200	$0	$1,200	$0
2	Fiber Optics	$1,200	$0	$1,200	$0
3	Colorimetric sensors	$1,200	$0	$1,200	$0
4	Hub assembly material	$1,200	$0	$1,200	$0
5	Contingency / Incidentals	$1,200	$0	$1,200	$0
6	Travel to forum	$3,000	$0	$3,000	$0
	Totals:	$9,000	$0	$9,000	$0
				Remainer of allocation	$0

Fig 3: Budget Calculations

Summer 2026, TRL 4:
Conclusion of HuLC

Year 0 of adoption, TRL 4-5:
Lab environment system validation

Year 1-2 of adoption, TRL 5-6:
High-fidelity habitat analog testing

Year 2-4 of adoption TRL 6-7:
Operational environment demonstration

Year 4-6 of adoption TRL 7-8:
Qualification of final design

Year 6-8 of adoption TRL 8-9:
Success in lunar environment

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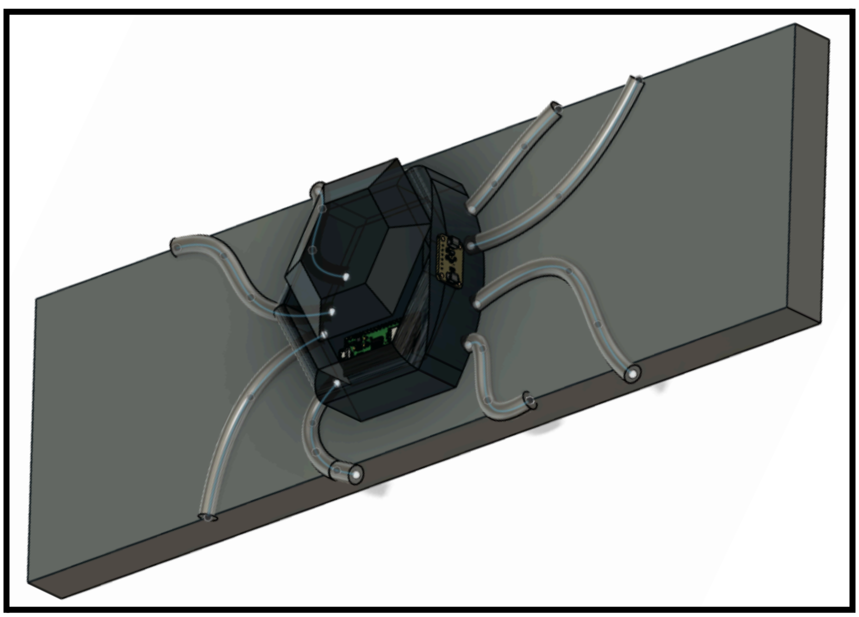


1. Executive Summary

Environmental control and life support system sensors used in current space habitats are reliable but often require multiple dedicated instruments, increasing system mass, power consumption, and operational complexity. For 30-day lunar surface missions, continuous monitoring of environmental hazards, including air quality changes, radiation exposure, and structural or fluid system faults, is essential to crew safety.

SPIDER (Sensor Package for Internal Detection in Extraterrestrial Regions) is a compact, multi-modal, wall-mounted sensing hub that integrates fiber optic, ultrasonic/piezoelectric, and colorimetric sensors into a single distributed monitoring system. By consolidating multiple sensing methods into one platform, SPIDER reduces sensor hardware redundancy while enabling real-time detection of environmental and system anomalies. The system offers a low-mass, low-power solution capable of monitoring multiple hazard pathways simultaneously, improving early detection and diagnostic capability. This approach directly supports Artemis objectives for sustained lunar exploration by enhancing habitat safety while minimizing resource demands.

2. Operational Context & Problem Definition

Sustained lunar surface missions are expected to support crewed habitation for approximately 30 days, with long-term evolution toward extended lunar presence and Mars missions lasting up to 1200 days. In these missions, Environmental Control and Life Support Systems (ECLSS) are mission-critical infrastructure. Continuous awareness of temperature, humidity, pressure integrity, air quality, and structural condition is required to ensure crew survival. Unlike low Earth orbit operations, lunar and Martian habitats must function with limited resupply, constrained power budgets, reduced gravity, and restricted crew time for maintenance. Monitoring systems must therefore provide reliable health awareness without imposing excessive integration or operational burden.

Although SPIDER sensor packages are intended for installation within the pressurized interior of a habitat, the broader exploration environment still drives design constraints. Systems must tolerate launch loads, long mission durations, vibration from rotating machinery, dust transported into the habitat, and radiation exposure. Over time, structural fatigue, small leaks, calibration drift, and gradual environmental shifts become more likely. Monitoring architectures must remain dependable and interpretable across these cumulative stressors.

Current space systems typically rely on distributed, powered point sensors that monitor hardware health using numerous temperature, pressure, humidity, and other dedicated sensing nodes. While effective, this approach scales through multiplication. Increasing monitoring confidence generally requires adding more sensors at more locations, which increases wiring, connectors, interfaces, and overall system complexity. Point sensors provide localized measurements, which can make anomaly localization difficult when issues develop between sensing nodes or propagate structurally. Many sensing channels also require continuous electrical power and periodic calibration, increasing baseline power demand and maintenance requirements. These characteristics create performance gaps for sustained lunar and Mars missions. Increasing sensor count to improve awareness can simultaneously increase integration burden, diagnostic ambiguity, and crew troubleshooting time. Limited spatial awareness can delay localization of developing leaks or structural anomalies. Continuous powered sensing reduces available operational margin in energy-constrained habitats. If these gaps are not addressed, future exploration missions risk higher operational complexity and slower response to off-nominal events. Even when safety is preserved, ambiguous or poorly localized indications can consume crew time and reduce mission efficiency. As missions extend in duration and autonomy increases, monitoring architectures must provide clearer, more localized system awareness without proportional growth in sensor count and system complexity.

This defines the central challenge addressed by this proposal: improving ECLSS hardware and environmental health monitoring while reducing reliance on numerous discrete, powered point sensors and the architectural burden they impose.

3. SPIDER'S Sensor Subsystems

3.1. Passive Power Harvesting

To minimize wiring complexity and reduce dependence on centralized power distribution, each SPIDER unit is designed to operate using passive energy harvesting combined with onboard energy storage. The primary energy source is a small photovoltaic cell that collects ambient interior lighting within the habitat. Typical spacecraft interior lighting is comparable to office environments; therefore, this design assumes a conservative illumination level of approximately 300 lux. Indoor-optimized photovoltaic cells operating under these lighting conditions can provide continuous trickle power sufficient to offset a portion of the SPIDER unit's operational load during normal mission conditions.

Each SPIDER unit includes a 1.67 Wh rechargeable battery to buffer harvested energy and provide reliable operation during periods of reduced illumination. In nominal operating mode, sensors are sampled at 1 Hz to monitor structural vibration, environmental conditions, and system health indicators. Data are processed locally and periodically transmitted to the habitat's central monitoring computer via Wi-Fi, while out-of-family measurements can trigger immediate alerts. Average power consumption in this configuration is estimated at approximately 49.5 mW. If ambient lighting were unavailable, the battery alone would support continuous operation for approximately 34 hours, while normal lighting conditions allow photovoltaic harvesting to partially offset this load and extend operational endurance. If interior lighting is lost or the system is commanded into contingency operation, the SPIDER unit transitions to a reduced-power emergency monitoring mode. In this configuration the system remains in deep sleep between measurements, reducing average power consumption to approximately 1.8 mW. Sensor data are only transmitted when measurements exceed defined safety limits, and a single daily health-status message confirms SPIDER functionality. With the onboard battery alone this mode supports approximately 38 days of operation, while additional harvested energy further extends endurance.

Supplemental harvesting is provided by a thermoelectric generator (TEG) mounted between the electronics package and the structural surface being monitored. Assuming a structural heat flux of 2 W/m^2 across a 50 cm^2 (0.005 m^2) device footprint, approximately 10 mW of thermal power is available. With a conservative conversion efficiency of about 2%, this yields roughly 0.2 mW of electrical power, with additional small contributions possible from electronics self-heating. This recovered energy reduces the net battery load and can extend emergency monitoring endurance to approximately 40–45 days.

To provide resilience in the event the battery becomes fully depleted, each SPIDER unit also includes a supercapacitor energy buffer. In this recovery mode, energy harvested by the TEG gradually charges the capacitor until sufficient energy is available to briefly power the microcontroller and sensors. SPIDER can then wake, read sensor values, and determine whether conditions remain within safe limits. Using this approach the system can perform periodic safety checks approximately every 10–15 minutes, enabling continued low-rate monitoring for as long as a thermal gradient across the structure persists.

Together, photovoltaic harvesting, thermoelectric energy recovery, and buffered energy storage enable SPIDER units to maintain long-duration monitoring capability while significantly reducing dependence on dedicated power infrastructure.

3.2. Ultrasonic/Piezoelectric Sensor for Location Detections of Anomalies

Structural monitoring entails detecting both the occurrence of disturbances and the location of their source. On the lunar surface, micrometeorite impacts, similarly to those that affect structures like the ISS, pose a significant risk of initiating microcracks that are difficult to detect and localize using traditional point sensors.

SPIDER addresses this challenge using an array of directional piezoelectric wafer active sensors (PWAS) mounted directly to the habitat structure. The system will triangulate the origin of acoustic emission events based on the arrival time differences recorded at each sensor node. Signal amplifiers and high pass filters are incorporated into each channel to suppress low frequency mechanical noise and reduce false alarm rates.

Power consumption for this subsystem is mainly driven by the signal amplifier circuit, which draws approximately 0.05 mA during active operation. The piezoelectric elements themselves are passive transducers that generate small voltage spikes upon mechanical excitation, and require no standby power at the sensor site. This low power consumption makes the ultrasonic subsystem useful to SPIDER's energy minimization objective.

3.3. Colorimetric Paint, XYZ Color Sensors, and Health-Centric Data Collection

In both lunar and terrestrial habitats, it is essential to monitor environmental changes that are not visible to the naked eye. For the SPIDER system, particular concerns include changes in air quality, ionizing radiation exposure, and the presence of aerosolized chemical compounds within human living spaces To monitor these hazards, our approach draws on the principles of traditional colorimetric sensing. Colorimetric films, textiles, and dyes are a well-established area of research that rely on materials which react to specific substances of concern, producing fluorescence or visible color changes when exposure occurs.

SPIDER leverages this concept through the development of specialized colorimetric coatings. One approach involves a fluoride-based compound paint designed to detect radiation exposure, while additional nanochemical colorimetric dye paints are used to identify aerosolized chemical compounds in the surrounding air. To measure these changes, SPIDER incorporates an XYZ color sensor that detects shifts in the colorimetric coatings. These color changes serve as indicators of airborne hazards or radiation in the monitored environment. The sensor is embedded within the central hub of SPIDER and observes a dedicated strip coated with the colorimetric paints, although future implementations may involve applying the coatings directly to exposed structural surfaces. At this stage of development, a dedicated sensor strip provides greater experimental control. The strip will be mounted parallel to the floor of the testing environment to reduce dust accumulation, which is a significant concern in lunar environments. The XYZ color sensor will be mounted at a slight angle beneath a transparent protective shield within the SPIDER hub, allowing an unobstructed view of the inverted strip. An integrated LED illumination source will provide consistent lighting conditions to ensure accurate color detection. The strip itself remains exposed to the surrounding air, allowing the coatings to respond directly to gaseous hazards and airborne particulates.

Through this system, SPIDER aims to provide a simple and reliable method for monitoring environmental hazards that may affect human health in lunar habitats.

3.4. Fiber Bragg Grating Optical Sensors and Data Interpretation

Walls of a lunar base architecture will likely consist of composite structural and inflatable layers for environmental protection (Rojdev et. al, 2009). This type of structure requires constant, low power monitoring systems to identify damage and environmental changes that can be caused by the thermal cycling and radiation experienced on the lunar surface. Fiber Bragg Grating (FBG) optical cable offers a well-tested and flight-validated solution for constant lunar health monitoring. FBGs have a long history of use for structural health monitoring (SHM) in analogous environments, such as in composite structures in Alaskan winter (Xiao et. al, 2017). FBG sensors have been applied and tested in space environments as well (Juwet et. al, 2024), proving sensor functionality in every application related to lunar base monitoring. FBG cables will provide a well-understood and tested baseline sensor to detect damage and structural abnormalities.

FBG cable sensors used in SHM can be dispersed over a large surface and can detect small changes in substrates. Bragg gratings have many benefits as a sensor in lunar structures, such as being resistant to electromagnetic interference and not requiring power or interrogation at the site of the sensor. For the SPIDER sensing project, this means that a single FBG interrogator can power an entire web of FBG optical sensors, which can be placed on any of the complex geometries that will be entailed in an internal lunar structure. Other sensing modalities within each node will allow for informed isolation of FBG signals for temperature or straining effects.

Fiber Bragg Gratings are formed by inducing a periodic modulation of the refractive index along the core of a single-mode optical fiber. This is usually accomplished through laser-produced partially reflective planes embedded within the optical fiber. The distance between reflective planes in the fiber is referred to as the grating pitch. An interrogator system induces light into the, and constructive interference occurs for light emissions at the same wavelength as the Bragg fiber pitch. Light emissions of the same wavelength as the Bragg pitch are reflected back toward the interrogator as a narrow spectral peak. On the opposite side of the grating, the optical spectra will have a missing peak at Bragg pitch. Both the reflected signal and the transmitted signal can be used for signal processing.

FBG sensing works by the changes in grating distance that occur when the cable experiences strain or other environmental changes. Axial strain stretches or compresses the Bragg pitch section of the cable, which will induce a phase shift in optical spectra data. Strain has additional effects on optical emissions, meaning a small change in surface stress can induce significant phase shift in FBG signals. Thermal expansion and temperature changes also affect optical transmissions, allowing for thermal anomaly detection through FBG sensing as well. Signal processing is usually accomplished through peak detection algorithms, such as cross-correlation or gaussian fitting. Arrays of FBGs along a single fiber with separate Bragg wavelengths allow simultaneous and distributed measurements of strain and temperature across an entire structure. Shifts in static strain fields can reveal load redistribution caused by crack initiation or delamination. Emissions from transient stress waves produced by crack propagation generate broadband signals that arrive at different FBG sensors with different time delays, which can allow damage localization,

4. System Architecture and Technical Design

Trade studies were conducted to evaluate whether SPIDER should employ a single sensing modality or a combined multi-sensor architecture. While minimizing system complexity is desirable to reduce potential failure pathways, the system must also provide reliable identification of multiple environmental hazards within a lunar habitat.

An Analytical Hierarchy Process (AHP) trade study was performed comparing four configurations: Ultrasonic/piezoelectric sensing only, colorimetric sensing only, fiber optic sensing only, and a triple-sensor configuration integrating all three modalities. Evaluation criteria included manufacturing complexity (16.83%), cost (5.12%), installation complexity (16.83%), robustness (30.61%), and reliability (30.61%), with robustness and reliability weighted most heavily due to the critical safety role of the system.

Table 1: AHP trade study tabulated criteria

Criteria	Weight	Ultrasonic Only		Colorimetric Only		Fiber Optic Only		Triple Combination S	
		Perf.	Wtd. Score	Perf.	Wtd. Score	Perf.	Wtd. Score	Perf.	Wtd. Score
Manufacturing Comp	16.83%	0.368	**0.062**	0.263	0.044	0.211	0.036	0.158	**0.027**
Cost	5.12%	0.280	**0.014**	0.280	**0.014**	0.240	0.012	0.200	**0.010**
Installation compl	16.83%	0.313	0.053	0.375	**0.063**	0.188	0.032	0.125	**0.021**
Robustness	30.61%	0.158	**0.048**	0.158	**0.048**	0.158	**0.048**	0.526	**0.161**
Reliability	30.61%	0.235	**0.072**	0.235	**0.072**	0.235	**0.072**	0.294	**0.090**
Sum:			0.249		0.242		0.200		0.309
Final Score:			81		78		65		100

The results indicate that while single-sensor systems perform well in simplicity metrics, they lack the robustness and redundancy required for reliable hazard detection. ultrasonic/piezoelectric-only and colorimetric-only systems achieved final scores of 81 and 78, respectively, while the fiber-optic-only approach scored 65 due to installation and manufacturing complexity. The triple-combination sensor system achieved the highest overall score (100). Although this configuration increases manufacturing and installation complexity, it significantly outperforms the alternatives in robustness and reliability, the two most heavily weighted criteria. The multi-modal approach also provides complementary sensing capabilities, allowing SPIDER to detect a broader range of hazards including structural disturbances, acoustic anomalies such as air leaks, and chemical or particulate contamination. Based on these results, the integrated triple-sensor architecture was selected as the optimal configuration for SPIDER, providing the most reliable and comprehensive hazard detection capability while maintaining acceptable levels of system complexity. Key metrics, such as mass and power requirements are organized with the table below:

Table 2: Key performance metrics

Estimate Type per one package	FBG sensors	Ultrasonic/ Piezoelectric Sensor	Colorimetric Sensing	Externals (casing, peripheral components)	Total, or highest overall required
Mass	30 grams	5 grams	40 grams	75 grams	149 grams
Amps	-	0.05mA	0.024 mA	18-30mA	50mA
Voltage	-	3.3V-5V	3.3V-5V	1.8V-5.5V	5.5V
Cost	$300	$4	$25	$40	$369

5. Technology Readiness & Development Plan

When evaluated against NASA's Technology Readiness Level (TRL) framework, SPIDER currently falls well below the maturity required for mission deployment. Our project presently stands at TRL 2-3, where active research and development are underway and key components, such as the fiber optic sensing elements, have been experimentally investigated. In contrast, technologies intended for operational space missions must typically reach TRL 9, indicating full system validation in a flight-proven environment.

Because SPIDER is designed to monitor environmental hazards that directly affect human safety, extensive validation is required before it could be considered mission-ready. Within the scope of this competition, our objective is to advance the system to TRL 4, where a prototype has been demonstrated and validated in a laboratory environment. To support this advancement, we have developed a structured development timeline for the duration of the competition. This timeline outlines the major milestones required to mature the technology from early-stage experimentation to a validated prototype system. A detailed timeline of team objectives during HuLC development is shown in appendix 5.

Following the HuLC competition, the SPIDER system is expected to reach Technology Readiness Level (TRL) 4, where individual components and subsystems have been validated in a laboratory environment. To progress toward mission implementation within the next 5–8 years, a structured technology maturation timeline has been developed. This roadmap outlines the steps required to advance SPIDER through progressively more realistic testing environments, including habitat analog demonstrations, environmental qualification, and ultimately flight demonstration. Each phase focuses on increasing system integration, reliability, and environmental validation to meet the standards required for human spaceflight hardware.

Table 3: mission ready scope timeline

Phase	Year	TRL	Goal	Key Activities	Exit Criteria
Post-HuLC Baseline	0	TRL 4	Component and subsystem validation in lab environment	Integrated prototype from HuLC competition; initial sensor calibration; baseline hazard detection demonstrations	Documented lab validation of integrated SPIDER prototype
Phase 1 – Environment Validation	0–1	TRL 4 → TRL 5	Validate integrated system in habitat-like environment	Build Gen-2 prototype; of color, ultrasonic, and fiber optic sensors; conduct testing and hazard simulations	Repeatable detection of hazards in relevant environment testing
Phase 2 – Prototype Demonstration	1–2	TRL 5 → TRL 6	Demonstrate prototype in high-fidelity habitat analog	Build Gen-3 prototype; integrate with habitat systems simulators; run long-duration tests; evaluate reliability	Documented system performance in habitat analog testing
Phase 3 – Operational Prototype	r 2–4	TRL 6 → TRL 7	Deployment-like system demonstrated in operational environment	Develop environment-like hardware; EMI/EMC testing; vibration and handling testing; dust ingress tests; integrate with habitat engineering test unit	Operational demonstration and verification reports
Phase 4 – Qualification	4–6	TRL 7 → TRL 8	Qualification of final design	Build qualification and flight units; thermal-vacuum testing; vibration and shock testing; finalize firmware and interfaces	Completion of qualification test campaign and readiness reviews
Phase 5 – Full implementation	6–8	TRL 8 → TRL 9	Demonstrate system in space environment	Deploy SPIDER in lunar habitat module; monitor environmental hazards during mission	Successful mission operation and performance verification

6. Verification, Validation & Risk

To ensure the SPIDER sensor package performs reliably, the system will undergo multiple cycles of verification and validation testing focused on its core performance parameters: hazard detection sensitivity, response time, sensor reliability, and multi-system integration. Because SPIDER is intended to operate within a climate-controlled lunar habitat environment, ground testing will primarily be conducted in air-conditioned, earth-atmospheric, laboratory conditions. Verification testing will evaluate each sensing modality individually before integrated system testing. Fiber optic sensing will be validated by mounting SPIDER to an aluminum structural testbed with secured fiber optic lines, allowing measurement of strain and structural disturbances while verifying installation stability and signal accuracy. Ultrasonic/piezoelectric testing will simulate controlled air leaks within the testbed structure to evaluate the sensors' ability to detect and localize acoustic signatures at varying distances from the source. Colorimetric sensing will be tested by exposing coated sensor strips to controlled concentrations of target hazards, verifying measurable color changes and sensor detection thresholds.

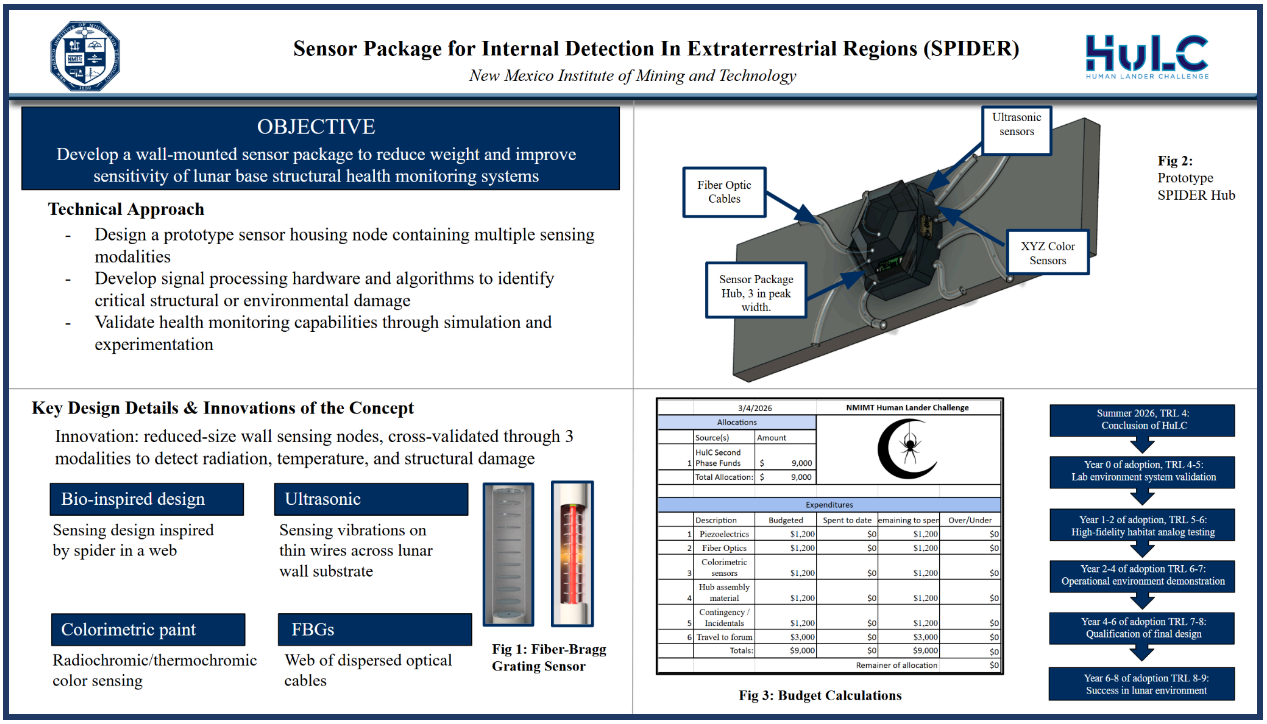
Following subsystem validation, the aluminum testbed will be used for integrated testing, where all three sensing systems operate simultaneously to verify coordinated hazard identification and system reliability. System acceptance will be determined by successful detection of test hazards within defined sensitivity and response thresholds while maintaining stable sensor output during continuous operation. Key risks include sensor integration complexity, detection sensitivity limitations, and schedule constraints associated with prototype fabrication. These risks will be mitigated through modular subsystem testing, early integration trials, and iterative prototype refinement throughout the development timeline. A detailed list of risks and a comprehensive risk matrix are shown in Appendix 3.

7. Mission Impact and Conclusion

The SPIDER system aims to reduce the size and cost of future lunar habitation health monitoring systems. This will be accomplished through a combination of flight proven and experimental, light-weight alternatives for structural and ambient health monitoring. The SPIDER unit is estimated to weigh around 150 grams with a margin of error of 50 grams . Each unit will consume around 50mA and 5.5V of power from batteries in each node. An external FBG interrogator and wireless networking terminal will likely consume around 12V and 1.25A off power. Each node will be able to service an area of around 50 square meters of habitat wall for structural and environmental anomaly detection. Each prototype will cost around $400 to build, and an expected $4 million would be required to develop the SPIDER into deployment-ready hardware, over a design and testing period of 6 to 8 years.

In the near term, SPIDER supports Artemis lunar surface mission objectives by providing continuous, low-resource environmental awareness within crewed habitats. In the long term, the architecture scales naturally to extended Mars missions, where resupply constraints and communication latency make autonomous, reliable habitat monitoring even more critical. The team will advance SPIDER from TRL 2 to TRL 4 through this competition, and will build on current work for environmental control and life system support for resource efficiency and anomaly detection capabilities.

8. Quad Chart



9. Appendices

Appendix 1: TLR Chart

Technology	2026	2027	2028	2029	2030	2031	2032
Fiber Bragg Gratings	8	9	9	9	9	9	9
Piezoelectric Wafers	5	6	6	7	7	8	8
Colorimetric Sensors	3	3	5	5	6	6	7
Raspberry Pi-Pico	8	8	8	9	9	9	9

TLR Chart 1: Predicted readiness of each utilized technology for in-space application

Appendix 2 : Budgets

	3/4/2026		NMIMT Human Lander Challenge		
Allocations					
	Source(s)	Amount			
1	HulC Second Phase Funds	$ 9,000			
	Total Allocation:	$ 9,000			
Expenditures					
	Description	Budgeted	Spent to date	emaining to spen	Over/Under
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6	Travel to forum	$3,000	$0	$3,000	$0
	Totals:	$9,000	$0	$9,000	$0
			Remainer of allocation		$0

Budget 1: competition scope budget

WBS	Description	Cost Driver	Source Factor
1.1	Concept & Requirements(Phase 1)	1.5 staff-months; $9,000 FTE-Yr (undergrad @ $6k/mo equivalent)	NAFCOM "Advanced Structures"; university stipend rate
1.2	Preliminary & Detailed Design (Phase 1 & 2)	4 staff-months + CAD/FEM licenses (~$500 student licenses)	NAFCOM multiplier 1.15x labor; student edition software pricing
1.3	Prototype & Sensor Fabrication (Phase 2)	FBG sensors x6, PWAS x10, colorimetric films x20, PCBs, Raspberry Pi Pico, other sensors	Vendor quotes: FBG ~$150/ea, PWAS ~$30/ea, Pico ~$5/ea, PCB ~$200 batch
1.4	Operational Prototype Testing (Phase 3)	EMI, EMC, Vibration testing	NASA SBIR Program
1.5	Qualification (Phase 4)	Thermal and shock testing at NASA facility	NASA CCRPP
1.6	Sub-scale & Bench-level Tests (Phase 4)	Lab bench time ~80 hrs, vibration fixture rental, data acquisition system	University lab rate ~$25/hr; DAQ rental ~$500; GSFC-STD-7000 ref.

WBS	Description	Cost Driver	Source Factor
1.7	Flight Demo (Phase 5)	Rideshare Costs	ISS CLD rideshare ICD reference
1.8	Mission Ops & Data Analysis	data review, 2 undergrad analysts	undergrad labor ~$20/hr x 200 hrs
1.9	Program Mgmt., QA, Systems Eng.	15% addition on WBS 1.1–1.6	NASA norm; advisor oversight included

WBS	Costs ($1000s)
1.1	9
1.2	25
1.3	2
1.4	200
1.5	400
1.6	300
1.7	3000
1.8	5
1.9	140
Total	4081

Budget 2: Mission readiness scope budget

All costs are preliminary placeholders based on NAFCOM parametric estimates, published vendor quotes, and standard university labor rates

Appendix 3: Risk matrix

Table 4: Risk evaluation matrix

Likelihood	5					
	4					
	3		6	3, 4		
	2					1
	1				2, 5	
		1	2	3	4	5
		Consequence				

Table 5: Description of identified risks

No.	Risk	Description	Mitigation
1	Sensor failure during deployment	Sensors may be damaged or improperly installed, preventing them from providing health monitoring data and potentially allowing damage to go undetected.	Prioritize ease of packaging and installation to reduce the chance of deployment errors.
2	Detection sensitivity limits	The sensor network may be installed successfully but still fail to detect critical health indicators within the system.	Use three complementary sensor modalities and perform testing in relevant environments to validate detection capability.
3	Design is too heavy	The sensor system may exceed mass limits, reducing the benefit of replacing existing methods.	Continuously optimize the design to minimize weight throughout development.
4	Design uses too much power	Excessive power consumption may be impractical for lunar habitat operations.	Select low-power components and prioritize energy efficiency in design decisions.
5	Sensor degradation in lunar environment	Radiation exposure and thermal cycling in lunar habitats may degrade sensor performance and reduce signal fidelity.	Ensure electronics and components are rated for lunar environmental conditions.
6	Noisy readings during mission	Differences between lunar habitat and lab conditions could produce unstable or noisy sensor signals.	Conduct thorough laboratory testing and calibration to stabilize signal interpretation.

Appendix 4: Project Timeline

Table 6: HuLC scope timeline

WBS NUMBER	TASK TITLE	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
1	Project Conception and Initiation				
1.1	Proposal paper due	2/25/26	3/4/26	9	100%
1.1.1	Prototype CAD iteration 1	2/1/26	3/4/26	33	100%
1.2	Prototype CAD iteration 2	3/4/26	3/17/26	13	30%
1.3	Bill of Materials (BoM)	3/11/26	3/20/26	9	40%
1.4	BoM and plan faculty review	3/23/2026	3/25/26	2	0%
1.5	Ordering and procurement period	3/25/26	4/6/26	11	0%
1.6	Project assembly and development	4/6/26	4/13/26	7	0%
2	Testing				
	HuLC Finalist teams announced	April--TBA			
2.1	Ultrasonic testbed assembly and testing	4/13/26	4/14/26	1	0%
2.2	Fiber Optic testbed assembly and testing	4/14/26	4/15/26	1	0%
2.3	Colorimetric testbed assembly and testing	4/15/26	4/16/26	1	0%
2.4	Triple-system integrated testing	4/17/26	4/24/26	7	0%
3	Reiteration period				
3.1	Mission-readiness asseseement	4/24/26	5/1/26	7	0%
3.2	Reiteration of design	5/4/26	5/15/26	11	0%
3.3	Assermbly period	5/18/26	5/20/26	2	0%
3.4	Problem-specific testing period	5/21/26	5/26/26	5	0%
3.5	Improvement period	5/26/26	5/29/26	3	0%
3.6	Status report for faculty	5/29/26	6/1/26	2	0%
4	Project Performance/Monitoring				
4.1	Deliverables prepared for HuLC forum	5/29/26	6/1/26	2	0%
	HuLC forum	June-- TBA			

Appendix 5: References

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