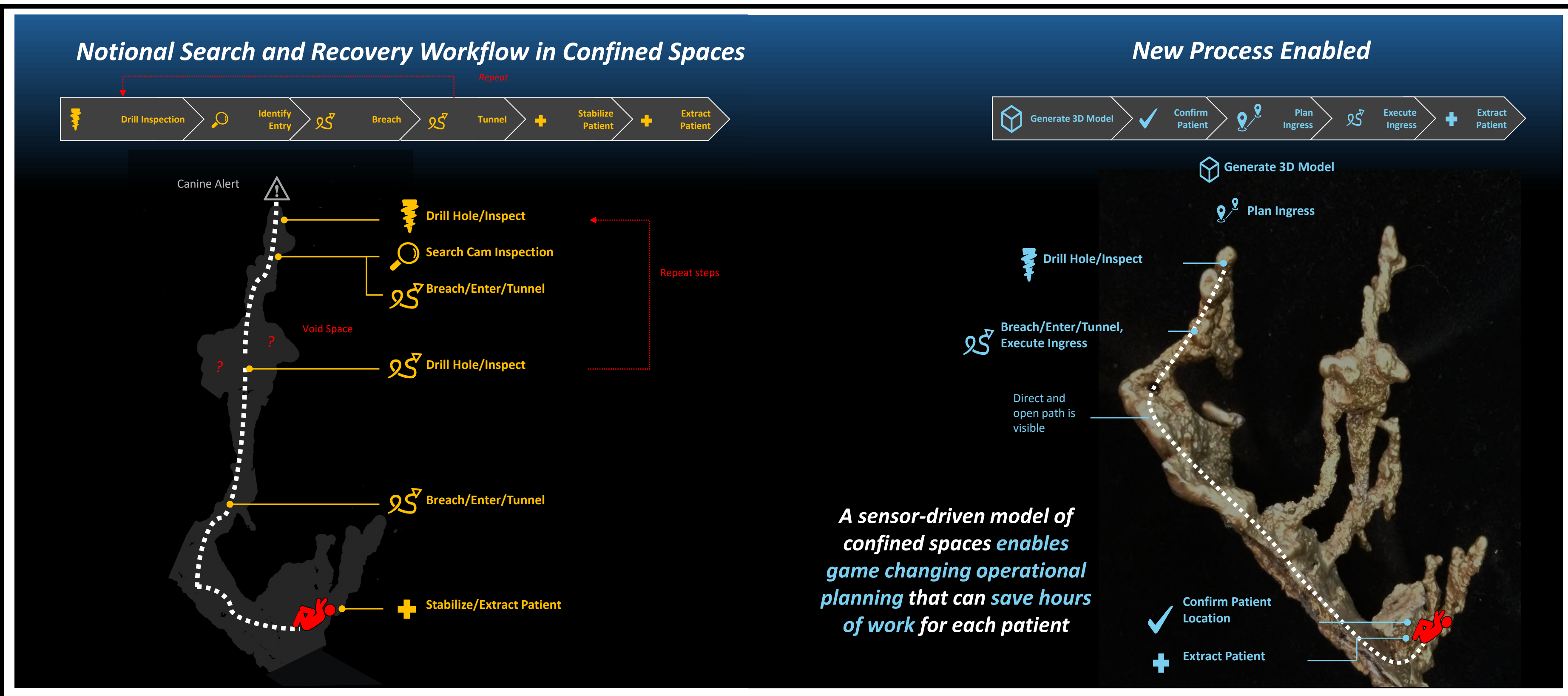


¹Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts, USA , ²University of Notre Dame, Notre Dame, Indiana, USA ³Stanford University, Stanford, California, USA

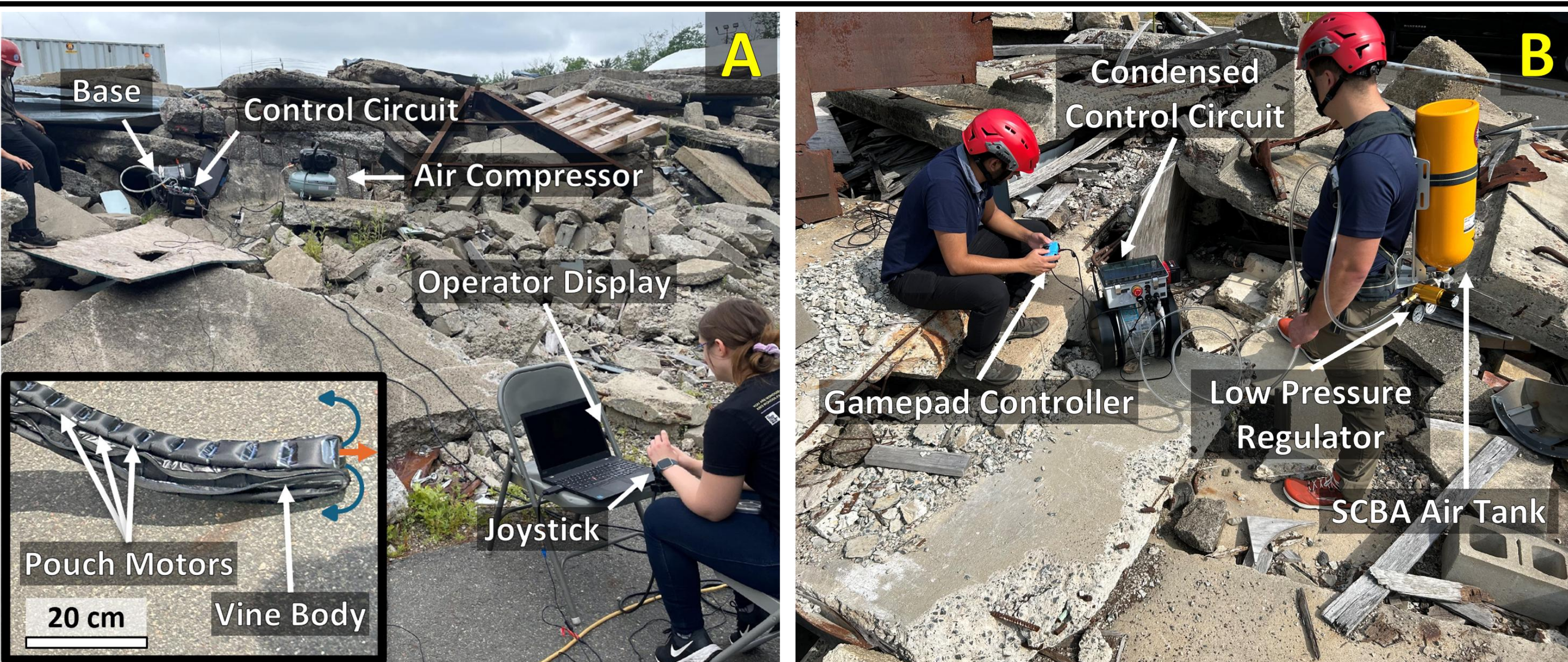
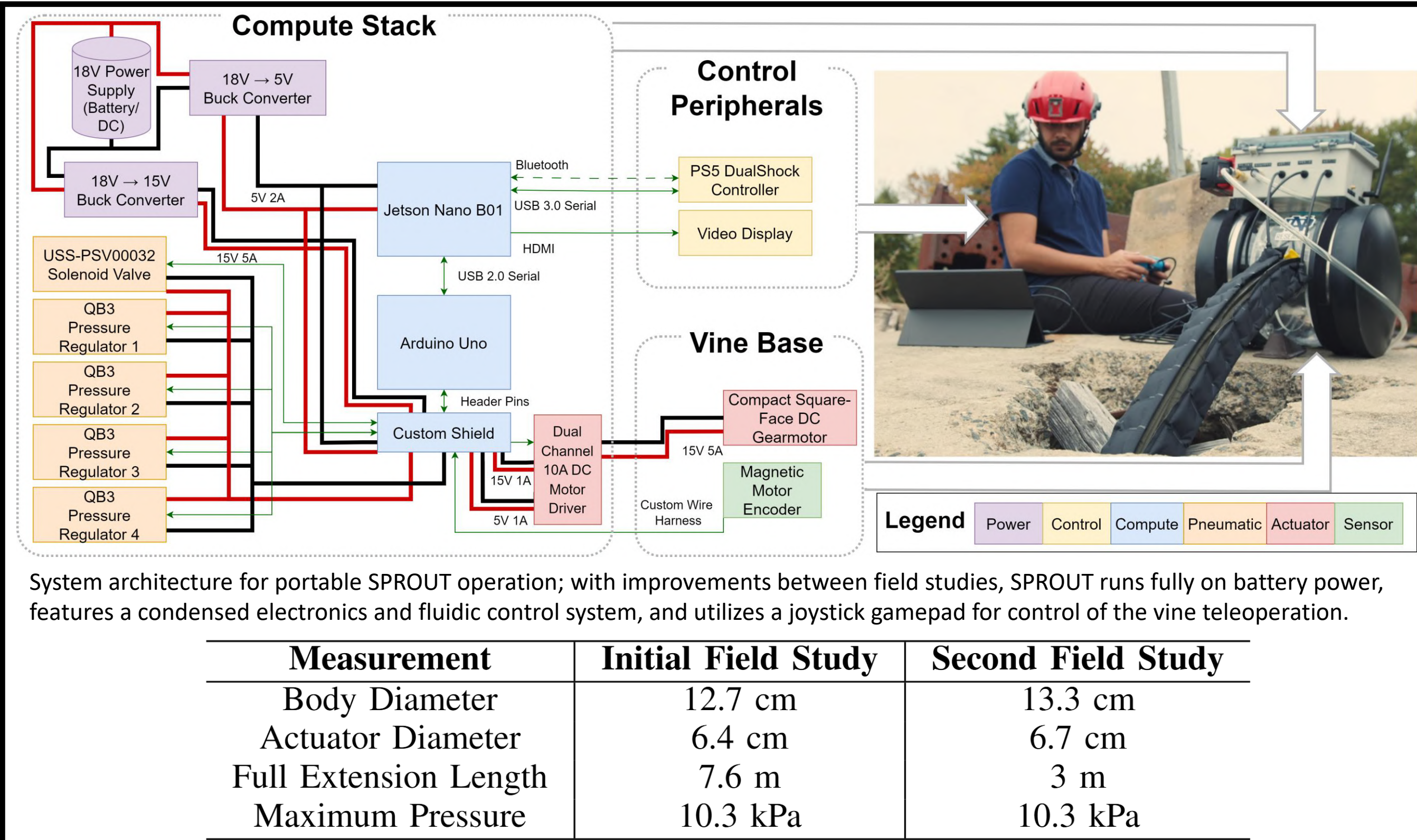
Introduction

- Vine robots are lightweight, inflatable robots that grow from the tip, enabling navigation through confined spaces and over long distances [1], but their application to urban search and rescue (USAR) has remained largely unexplored [2]
- In this work, we demonstrate the deployment of SPROUT (Soft Pathfinding Robotic Observation Unit) in realistic USAR scenarios
- Through two field exercises, we evaluated system performance and introduced improvements in durability, portability, and operational readiness toward practical field deployment [3]

Structural Collapse Ingress



System Architecture and Hardening



Experimental setup for field studies. (A) The SPROUT system that we tested in the initial field study consists of a base containing the spooled vine body, a portable air compressor, and control electronics in separate cases. The operator controls the system with a joystick while viewing the tip-mounted camera stream on a screen, allowing safe operation if the entry point into the pile is unstable or hazardous. (Inset) View of SPROUT with tip camera removed showing the principle of growth by eversion. (B) Improved SPROUT system incorporating feedback from USAR team members and insights from the first study. The system condenses control electronics into an ingress-protected container that mounts to the top of the pressurized vine base. A self-contained breathing apparatus (SCBA) tank provides compressed air to grow and steer the robot.

Testing Procedures

Level	Description	Human Challenge	Vine Robot Challenge	Test
1	Completely straight path	Easy	Easy	1, 2
2	Horizontal path between entry and destination	Easy	Easy	1, 5, 6
3	Horizontal path becomes vertical and down	Medium	Easy	3, 4
4	Vertical entry point	Hard	Easy	2, 3
5	Entry point too small for a human	Impossible	Easy	3, 5, 6
6	Loose debris or thin obstacles (rebar/cables)	Medium	Easy	4, 6
7	Pooled water or slurry	Medium	Medium	-
8	Utility hazards (live electricity, gas leak, etc.)	Hard	Unknown	-

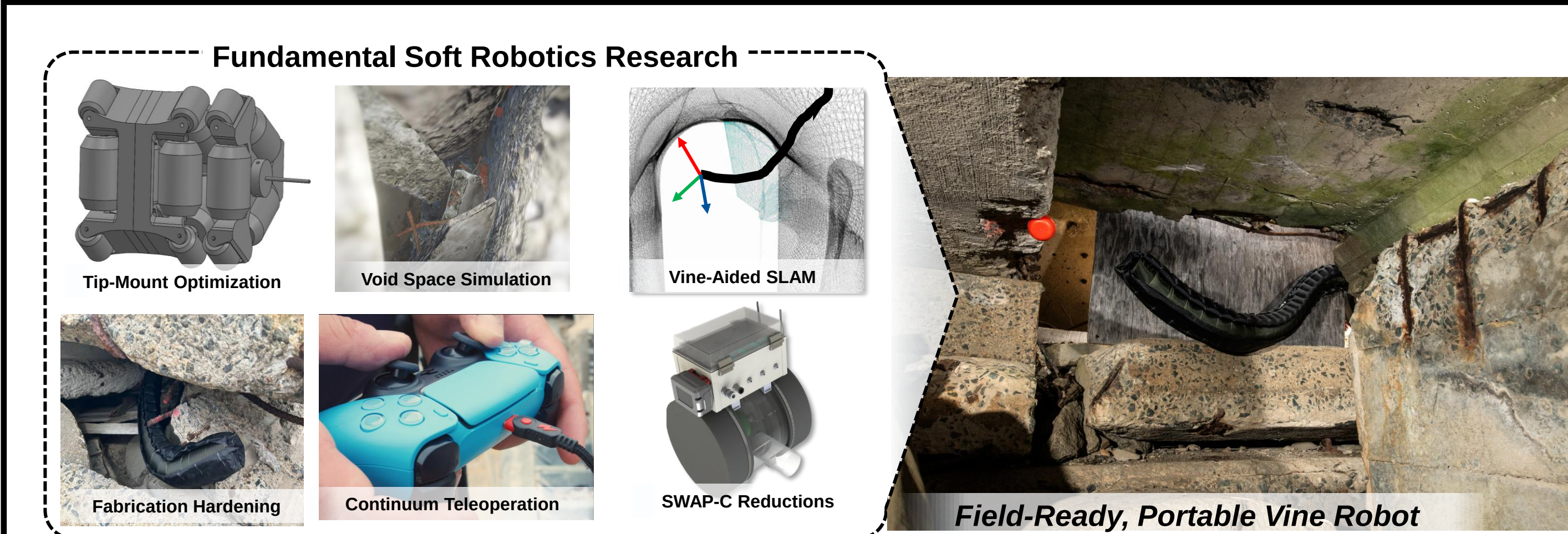
Taxonomy of difficulty for void space entry for humans and vine robots

Test locations on Massachusetts Task Force 1 rubble pile. We tested SPROUT at six locations on the mock collapsed structure rubble pile in Beverly, MA, each corresponding to different levels on the taxonomy of difficulty from Table (above). The top and bottom rows of images present close-up views of the trial locations from the second field study (B) and the initial field study (A). The middle image is a birds-eye view of the rubble pile. Map data: Google 2024.

Field Observations

Initial Field Study	Second Field Study
Test 1: SPROUT grows to 3 m over obstacle and around sharp corner Test 2: Traverses shiftable debris; with camera mount, collapses in free space Test 3: Makes a sharp unsupported turn through cement tubing	Test 4: Grows over an abrasive obstacle and makes a 180° turn Test 5: Extends through a small aperture and bends over obstacles Test 6: Grows to full length over hazardous rebar to find entry
Desired USAR Capability - Long Reach (>3 m) - Tortuous Path Traversal - Tip-Mounted Sensing - Fits Through 6.4 cm Drill Hole - Remote Teleoperation - Intuitive Control - Portability - Durability - Speed	SPROUT Robot - Demonstrated to 3 m, longer possible - Completed multiple paths with turns - Collected visual information, but camera mount weight (145 g) restricted steering - Camera mount was 8.5 cm wide and could not compress - Demonstrated 8.4 m between human operator and robot base via wired connection - Situational awareness challenging from tip camera image alone - Portable with a two-person team - Robot lasted through second field study, no damage from environment 2.5 m/min growth, slower with camera mount
Key findings from experiments. Without the camera mount, SPROUT steered in all directions and grew around sharp turns. With the mount, SPROUT had more limited tip mobility. With the hardware improvements between the field studies, SPROUT exhibited more capable maneuverability, faster growth, and more reliable teleoperation.	

Conclusions and Future Work



- SPROUT improves responder access to confined and difficult-to-reach areas within collapsed structures
- Enhancements to system durability and portability enabled more reliable operation and single-operator deployment
- Future work will focus on void-space mapping and developing more intuitive teleoperation interfaces for first responders

References

[1] E. W. Hawkes, L. H. Blumenschein, J. D. Greer, and A. M. Okamura, "A soft robot that navigates its environment through growth," Science Robotics, vol. 2, no. 8, ean3028, 2017.

[2] M. M. Coad, L. H. Blumenschein, S. Cutler, J. A. R. Zepeda, N. D. Naclerio, H. El-Hussieny, U. Mehmood, J.-H. Ryu, E. W. Hawkes, and A. M. Okamura, "Vine robots: Design, teleoperation and deployment for navigation and exploration," IEEE Robotics & Automation Magazine, vol. 27, no. 3, pp. 120–132, 2020.

[3] C. McFarland, A. Dhawan, R. Kumari, C. Council, M. Coad, and N. Hanson, "Field insights for portable vine robots for search and rescue," in IEEE International Symposium on Safety, Security and Rescue Robotics, 2024.

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