Integrated Wearable Sensing Garment for Continuous Decompression Sickness Monitoring

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Mission Statement

To enhance astronaut health and mission safety in microgravity environments by developing a smart textile with integrated flexible sensors for continuous, non-invasive physiological monitoring and by using real-time collected data to identify physical strain and inform decisions regarding fatigue management.

What is Decompression Sickness (DCS)?

- DCS occurs when there is a rapid decrease in pressure that causes dissolved nitrogen in the body to form gas bubbles [1]
- These nitrogen bubbles move into blood vessels and tissues, creating venous gas emboli and causing pain, breathing issues, and disrupting circulation
- Astronauts are at the highest risk of DCS when transitioning between higher-pressure spacecraft environments and EVA suits [2]

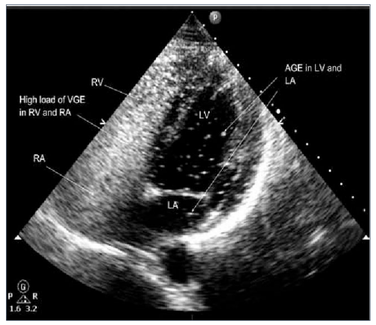


Figure 1. Nitrogen microbubble formation in the left ventricle [1]

Why DCS Monitoring Matters

- NASA's Exploration Atmosphere uses 8.2 psia and 34-37% O_2 to support high-frequency EVAs, but reduced pressure exposure increases the risk of decompression sickness and venous gas emboli [2]
- In one NASA model of a 6-hour EVA at 4.3 psia, estimated incidence was 3.1% for DCS and 23.2 for VGE [3]

Goal

Develop a minimally invasive Doppler ultrasound technology coupled with other sensors in a wearable garment monitoring the risk of decompression sickness by identifying the presence of venous gas emboli (VGE) in blood vessels

Current Market Solutions

- Astroskin — multi-sensor smart garment
  - No real-time evaluation of DCS risk [4]
- BioHarness — chest-strap physiological monitor
  - Poor skin contact, unreliable data [5]
- Prebreathe Protocol — current DCS prevention countermeasure
  - Time-consuming (4 hours)



Figure 2. Astroskin



Figure 3. BioHarness

Proposed Solution

A sensor-integrated compression garment that combines continuous-wave Doppler ultrasound at the left and right subclavian veins with ECG, SpO2, and respiratory sensing to monitor DCS.

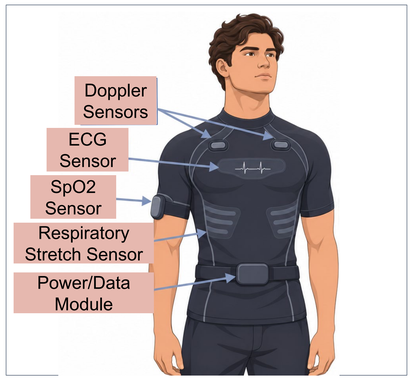


Figure 4. Drawing of proposed solution

Table 1. Abbreviated design specifications based on user needs

Metric No./ Need	Metric	Ideal Value
3.1/ Heart rate accuracy **3.2/ Respiratory Rate** **3.4/ SpO_2 accuracy** **3.6/ VGE Grade**	3.1/ Error in beats per minute 3.2/ Error in breaths per minute 3.4/ RMS of SpO_2 and reference 3.6/ Linear-weighted kappa between algorithm and expert	3.1/ ± 2 bpm 3.2/ ± 1 brpm 3.4/ ≤ 3.0 % A_{rms} 3.6/ kw ≥ 0.69
5/ Battery life	5/ Functional time after charging	5/ ≥ 7 days
6/ Power consumption	6/ Average power consumption in mW	6/ ≤ 20 mW
9.1/ Continuous recording	9.1/ Hours of uninterrupted/charge cycle	9.1/ ≥ 48 hours
10.1/ Data transmission **10.2/ Data preservation**	10.1/ % of data packets successfully received	10.1/ ≥ 99% 10.2/ ≥ 48 hours

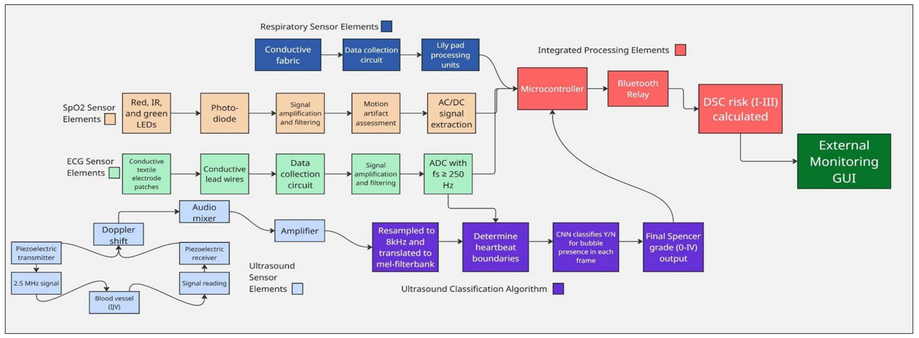


Figure 5. Proposed solution workflow

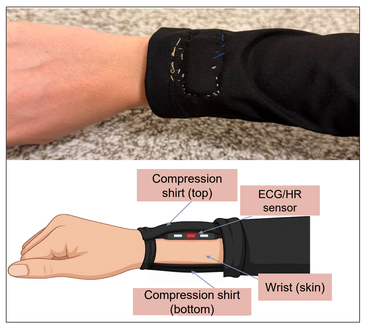


Figure 6. Proof-of-concept compression garment and cross-sectional diagram

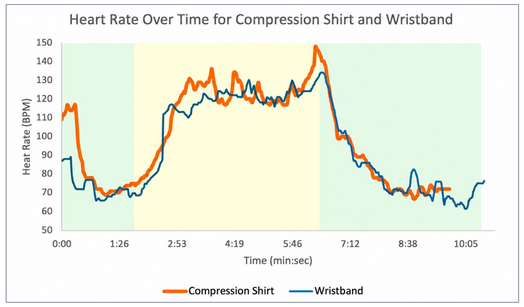


Figure 7. Heart rate proof-of-concept data

- Doppler Ultrasound circuit schematics were created using MultiSim (Fig. 8).
- Small ML pipeline (Fig. 9) trained on synthetic data [6] detects bubble events in each frame and quantifies them to classify VGE severity on the Spencer scale (grade 0-IV) → mimics clinician thought process

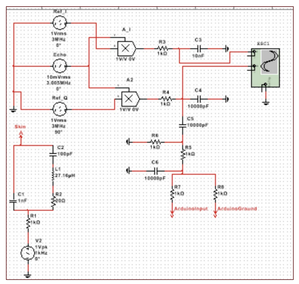


Figure 8. Doppler circuit schematic

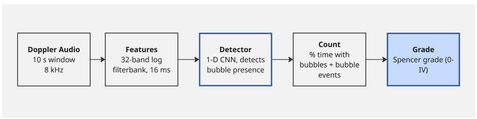


Figure 9. VGE classification pipeline

Table 2. Summary of pipeline performance

Accuracy (Exact Grade)	Accuracy (Within 1 Grade)	Precision	Recall	F1 Score
0.78	0.96	0.93	0.92	0.93

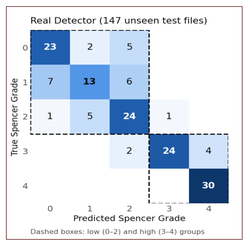


Figure 10. Preliminary evaluation of 1-D CNN shows promise

Proof of Concept

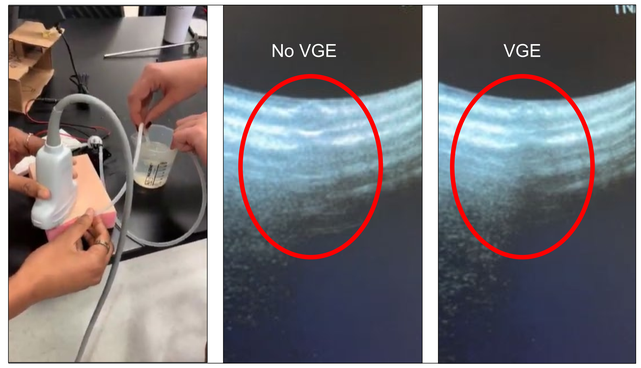


Figure 11. Pre-test setup confirmed with pre-built Doppler ultrasound

Test Setup

- A 10% ballistic gelatin phantom containing two 6.35 mm OD / 4.76 mm ID natural latex tubes represents the target subclavian vein and a nearby non-target vessel
- A fluid reservoir and peristaltic pump circulate blood-mimicking fluid through both channels to create controlled flow
- The Doppler ultrasound probe will be positioned over the target vessel to collect flow signals; the neighboring vessel provides a discrimination challenge
- Controlled air bubbles are introduced into the venous line to simulate VGE and evaluate bubble detection

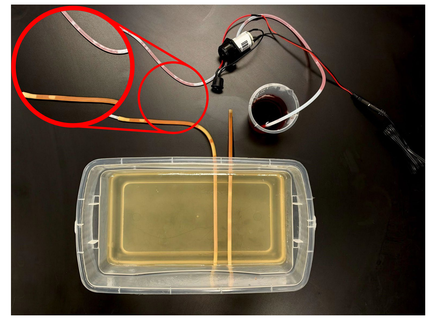


Figure 12. Doppler flow phantom for subclavian VGE detection testing

Conclusions

- ➢ Feasibility of the test setup was confirmed via proof-of-concept testing using a pre-built Doppler Ultrasound
- ➢ 1-D CNN showed promising results (78% accuracy, 96% within ± 1 grade) using synthetic VGE audio
- ➢ Circuitry that is capable of replicating Doppler Ultrasound mechanisms has been modeled and proven to work via Multisim schematics
- ➢ SpO2, Respiratory Stretch, and ECG sensor designs were validated via POC creation and testing
- ➢ Baseline method of integrating sensors to form factor has been established

Future Work

- ❑ Doppler ultrasound prototype and classification algorithm evaluation using phantom test setup
- ❑ Finalize garment form-factor, textile, and sensor integration

Acknowledgements

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References: [1] "Risk of decompression sickness." National Aeronautics and Space Administration. https://www.nasa.gov/reference/risk-of-decompression-sickness/ (accessed Sept. 9, 2026). [2] A. Abercromby, M. Gernhardt, and J. Conkin, "Fifteen-minute Extravehicular Activity Prebreathe Protocol Using NASA's Exploration Atmosphere (8.2 psia / 34% O2)," Acta Astronautica, vol. 109, 2013, doi: 10.1016/j.actaastro.2014.11.039.
[3] J. Conkin, "Probability of decompression sickness and venous gas emboli from 49 NASA hypobaric chamber tests with reference to exploration atmosphere," NASA Johnson Space Center, Houston, TX, USA, NASA NTRS 20200004317, Apr. 2020. [4] Hexoskin, "Astroskin Vital Signs Monitoring Platform for Advanced Research." [Online]. Available: https://hexoskin.com/pages/astroskin-vital-signs-monitoring-platform-for-advanced-research. [Accessed: Sep. 11, 2026].
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