Self-Sensing, Shape-Morphing Respiratory Ventilator Using Hydraulically Amplified Self-Healing Electrostatic Artificial Muscles

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Diaphragm dysfunction is a major cause of respiratory failure, affecting millions of patients worldwide. Current assistive solutions rely on invasive approaches with high complication rates, reducing quality of life. This work fulfills an urgent need for therapeutic, biocompatible ventilation options by presenting a self-sensing, shape-morphing soft-robotic ventilator based on hydraulically amplified self-healing electrostatic (HASEL) actuators. HASEL’s soft structures and self-healing properties enhance reliability and performance, conforming to the diaphragm’s curvatures with minimal disruption of surrounding tissues. The ventilator is fabricated using direct-ink-write 3D printing. A polyethylene glycol-based sacrificial material is introduced to enable internal geometries. Thermally-elongated core-shell nozzles are also developed, increasing printable resolutions by 5x and enabling adaptation to patient-specific dimensions. The ventilator integrates a variable-stiffness shape-morphing base, whose pressure-responsive layer jamming adapts to mechanical demands and stabilizes applied forces throughout the respiratory cycle. A soft, piezoresistive sensor is designed and integrated for closed-loop, predictive control via machine learning while preserving the system’s compliance and demonstrating minimal hysteresis due to a fluidic reset mechanism. The ventilator produces strains of 89.7% and achieves frequencies of 7.5 Hz, providing sufficient assistance. Its characteristics can be further optimized via finite element modeling simulations. Overall, this work establishes a framework for sensing and device personalization that advances the state of diaphragm-assist systems and soft robotics, enabling adaptive, intelligent, and biocompatible biomedical systems.

Awards Won:

Fourth Award of $600