A Digital Design Approach to Produce an Automated and IoT-Enabled Resuscitator for COVID-19 Emergency Uses

D. Shah, T. Sullivan, A. Nork, R. Rouf, T. Hasan, H. Khezam, I. Shahriar, T. Caton, G. Coolidge, E. Tekerek, V. Perumal, E. Caglan Kumbur, J. Yasha Kresh, P. Huang Zhang, and A. Kontsos

Theoretical and Applied Mechanics Group, Department of Mechanical Engineering & Mechanics, Drexel University

Introduction

The onset of the COVID-19 pandemic prompted an unprecedented demand for medical equipment capable of combating the effects of acute respiratory failure. The pandemic resulted in:

- A short supply of fully-featured ventilators typically used in hospital settings
- An increased use of manual bag valve mask (BVM) resuscitators (i.e., Ambu bag) that provide rapid-response respiratory support
- A need to alleviate the manual operations of BVM-style resuscitators

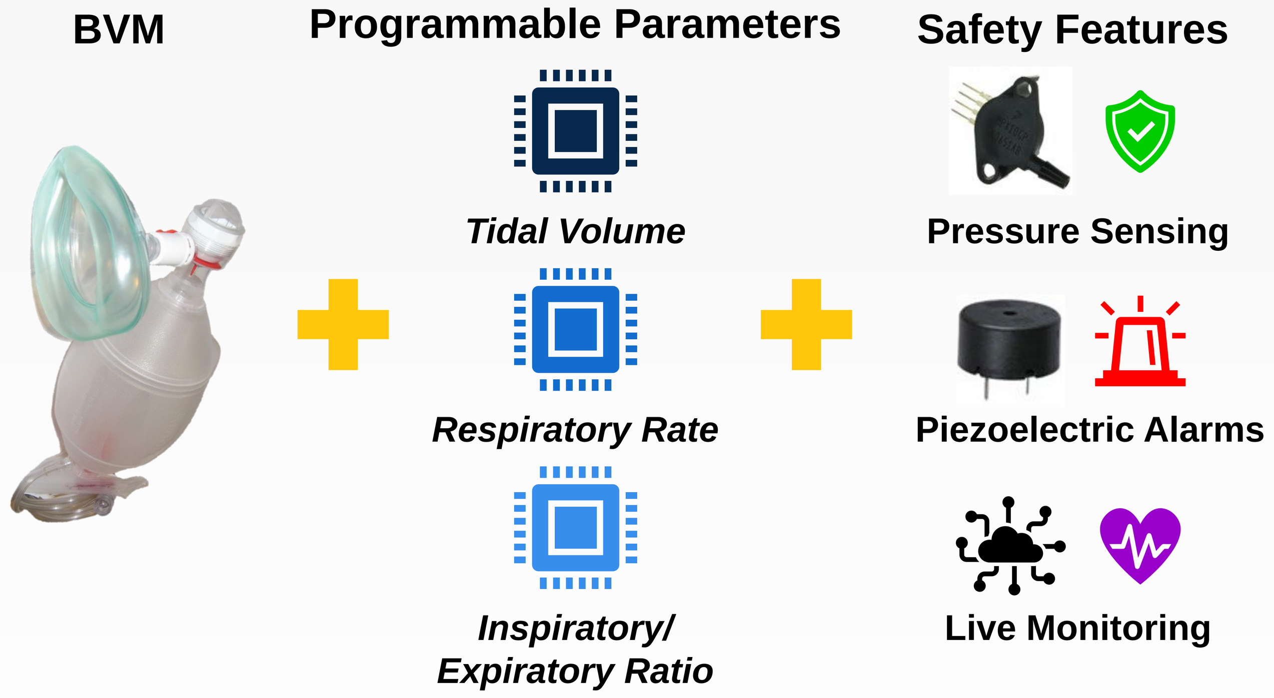
The **Dragon Resuscitator** developed at Drexel University is a portable, inexpensive, and automated respiratory support device that combines programmable features with an FDA-approved BVM to mechanically assist patient breathing.

Goal

Design, manufacture, and test a portable, inexpensive, and automated respiratory support device that utilizes:

- A **digital design and distributed additive manufacturing approach** to streamline iterations and assemble physical prototypes for testing.
- **Product lifecycle management (PLM) methods** to document the core design workflow and record process-critical tasks required to achieve a functioning prototype.

Key Performance Requirements

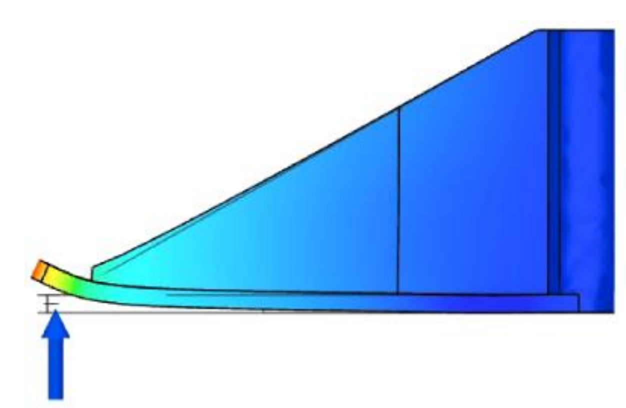


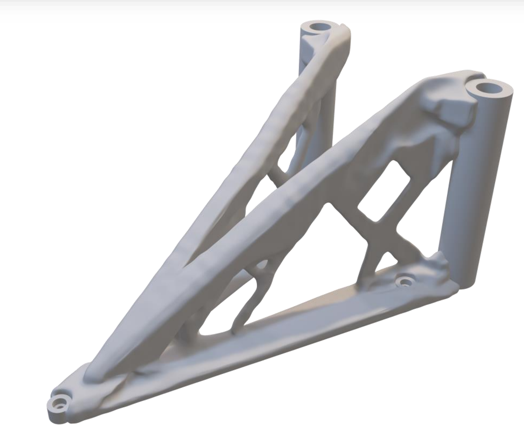
Design Requirements

The components follow an iterative digital design process with interconnected phases. As a case study, the evolution of the device's compression gantry stabilizer is presented in the context of a 3-phase design sequence: Design, Simulate, and Optimize.

Technical Approach

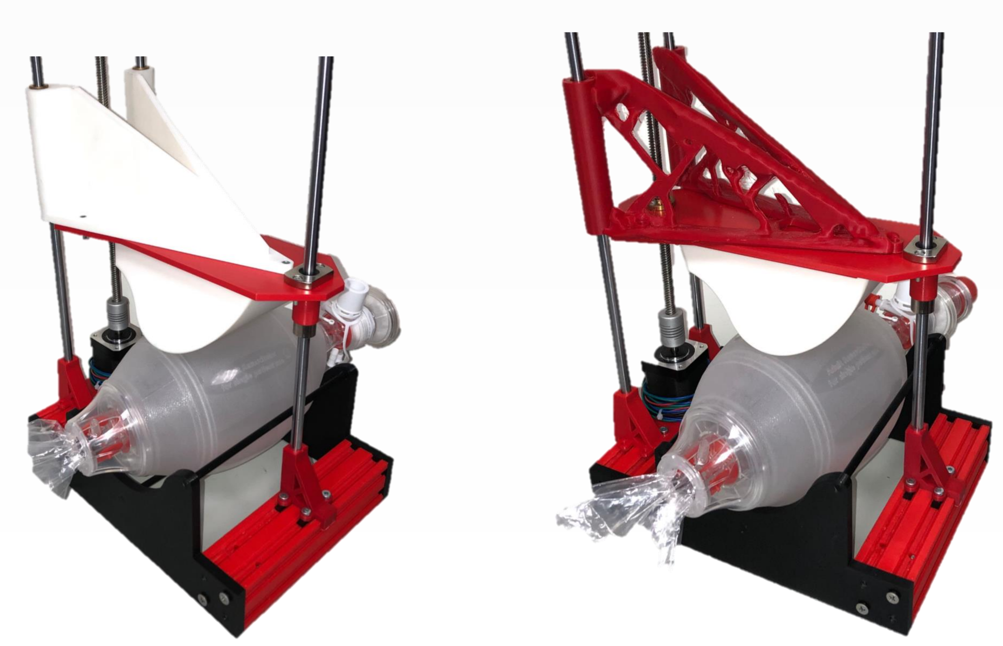
Design	Simulate	Optimize
Identify need for stabilization component based on design performance	Experimentally collect physical load case data	Determine component potential for optimization
Design component to address device deficiency	Apply anticipated load cases to computational analysis model	Define optimization criteria: ▪ Minimize Mass ▪ Maximize Stiffness
Digitally test-fit the component in the full assembly	Review results including safety factor, displacement, and stress	Define manufacturing and material constraints to produce manufacturable outcomes





Digital Design Evolution

Additive Manufacturing and Physical Assembly



Stabilized *Optimized*

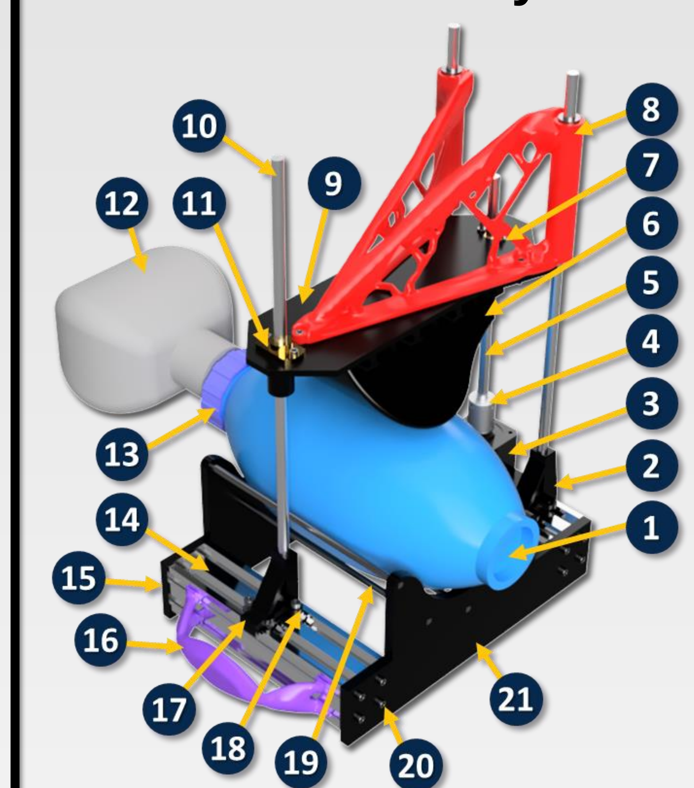
Using the outlined digital design workflow, the pictured prototypes were assembled using a combination of commercially available parts and custom components that were designed for manufacturing on a fused deposition modeling (FDM) 3D printer. Using computational analysis tools and digital assemblies enabled the team to minimize the transitions between the digital and physical workspaces.

Results & Discussion

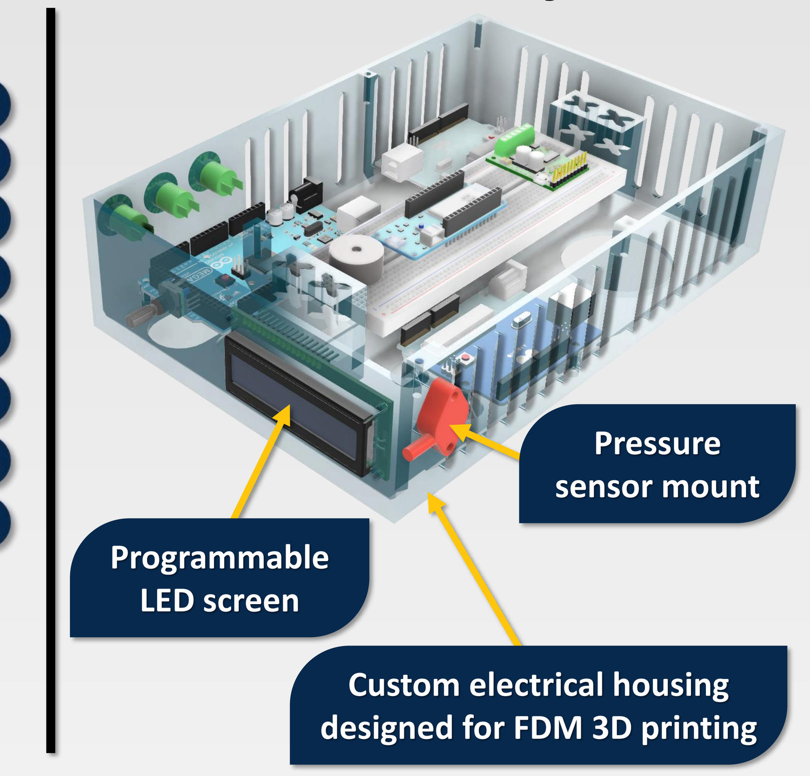
The outcome of implementing this rapid digital design process was a completed and manufactured prototype that was ready for testing.

- PLM methods are incorporated to package individual design workflows for any given component within the Mechanical Subsystem.
- Similar design process was used to design a custom 3D printed housing for the Electrical Subsystem inclusive of all electrical components and performance features.

Mechanical Subsystem



Electrical Subsystem



Future Work

Immediate next steps include:

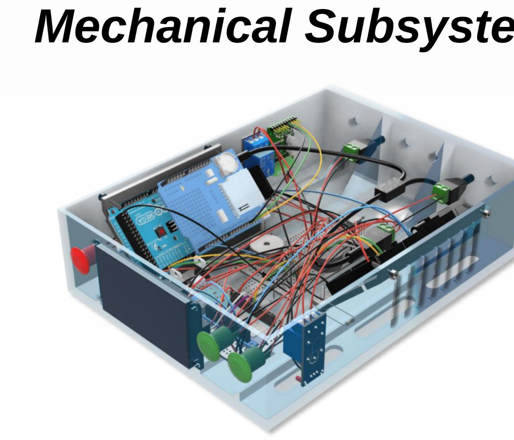
- Conducting benchtop tests to evaluate the device's ability to meet medical and regulatory requirements.
- Developing a second version of this device based on the physical performance of the current model. This version is being designed to be more compact and easier to manufacture.

Testing Requirements

- *Government Regulations*
- *Benchtop Testing*
- *Clinical Approvals*
- *Mass Manufacturing*

Dragon Resuscitator 2.0

Mechanical Subsystem



Electrical Subsystem