Stimdia Medical: Patient Diaphragmatic Lung Simulator

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ABSTRACT

Current mechanical test lung does not simulate patient effort needed in order to to test Stimdia Medical's pdSTIM system.The goal was to design a system to simulate patient diaphragmatic effort at different lung compliances with a Michigan Instruments Test Lung (MITL). A brushed DC motor was utilized to raise the bellows of the MITL to generate the pressure due to diaphragmatic effort (P_{mus}). A working system was able to generate a P_{mus}, but was unsuccessful in meeting the desired accuracy design constraints.

PROBLEM STATEMENT

Stimdia Medical engineered the pdSTIM phrenic nerve stimulator device to alleviate issues associated with mechanical ventilation. Stimdia's current device does not take into account patient effort from mechanically ventilated patients. To improve the next design interaction, a method to model patient effort should be produced. In an attempt to incorporate a functionality where limited patient effort can be accounted for, the team was tasked with modifying a mechanical lung to model breath waveforms.

BACKGROUND

BIOLOGY AND PHYSIOLOGY

- During inhalation, the dome-shaped diaphragm contracts to generate a subatmospheric pressure, drawing air inward. During exhalation, the opposite occurs [1].
- The subatmospheric pressure generated in the lungs by the diaphragm varies with the compliance of the lungs. A normal adult lung compliance is 100 mL/cmH_2O, but it can vary if the person has a disease like pulmonary fibrosis or emphysema [2].
- Ventilator-induced diaphragm dysfunction (VIDD) has been shown to result from mechanical ventilation, and phrenic nerve stimulation has been shown to reduce ventilation time and improve patient outcomes [3].

DESIGN RESEARCH

- Initial testing was done on the lung to determine what torque the motor would need to produce to reach the lung pressures this project aims to model
- A brushed DC motor, power supply, and current controller were selected based on their ability to meet the force requirements for the lung and their ability to interface easily with each other
- Simulink and a National Instruments DAC were chosen to send signals to the motor because of their simplistic interface ability within a graphical programming language that supersedes traditional languages

DESIGN CRITERIA

ACCURACY

- The design must be accurate within ±1 cmH_2O of a desired pressure

PERFORMANCE

- The device must be able to generate a vacuum pressure of up to 50 cmH_2O
- The device must produce breath waveforms that take inputs of breath rate, inspiratory time, waveform selection, lung compliance, and the minimum P_{mus} during exhalation

SAFETY

- All components of the device must be compatible and checked so that the high torque and power requirements do not start a fire or damage the MITL

LIFE IN SERVICE

- The device must produce repeatable results for as long as its components are expected to last

FINAL DESIGN

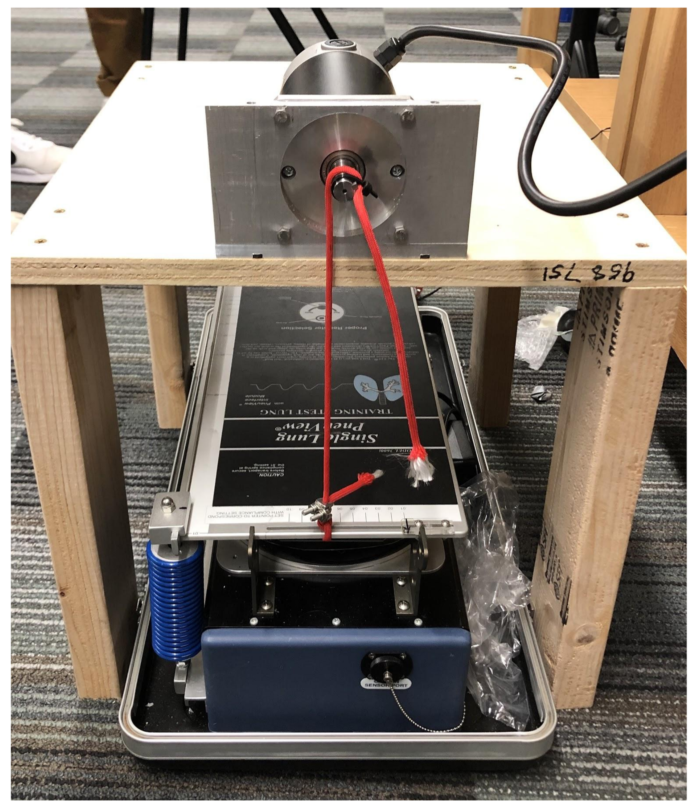

Figure 1. The motor mounted on a stand, connected to the MITL

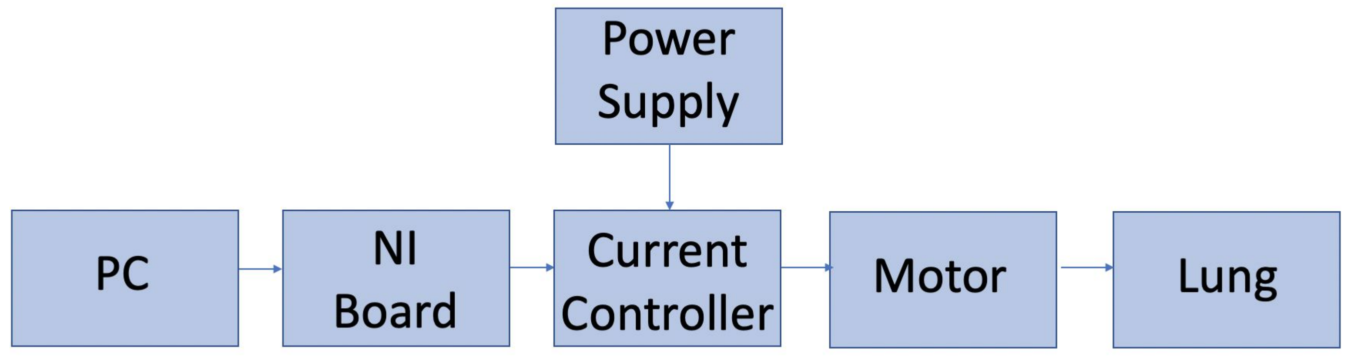

Figure 2. A block flow diagram showing the connections between different elements of the device

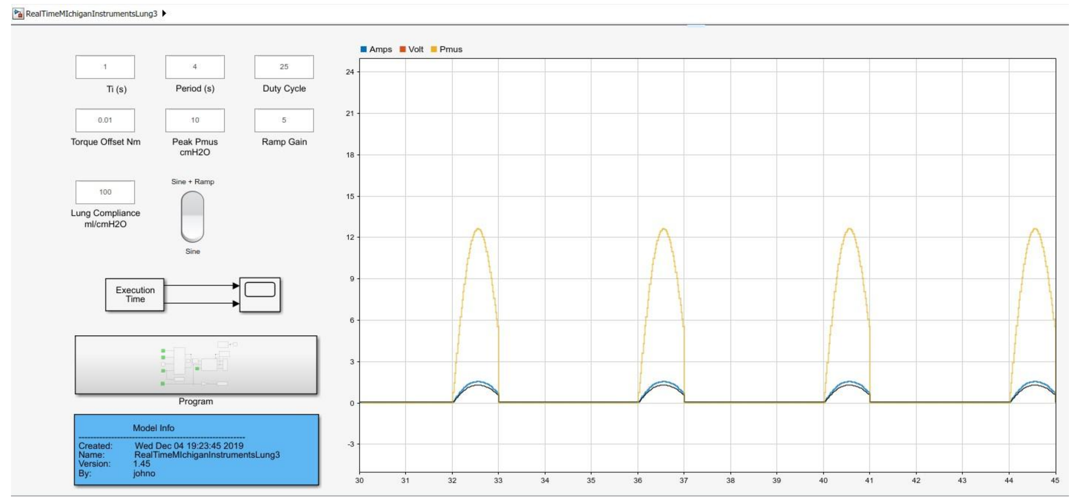

Figure 3. The Simulink GUI, showing the inputs selected and waveform output

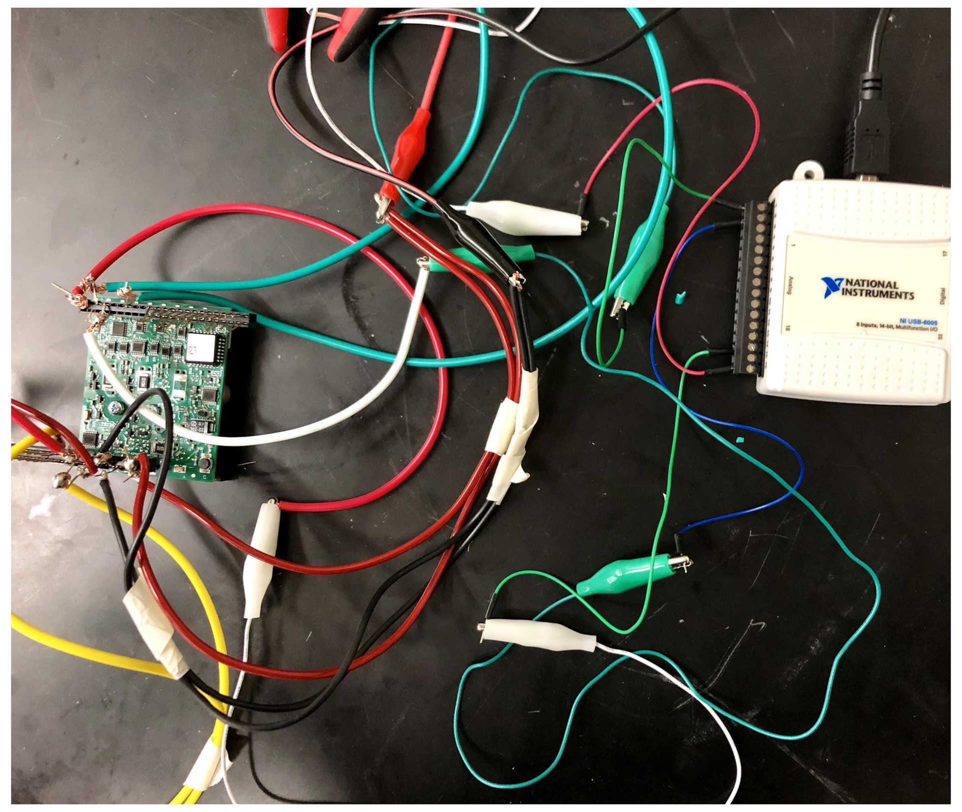

Figure 4. Design circuitry, with the current controller (left) wired to the NI DAQ device (right)

TESTING AND RESULTS

PROCEDURE

- The lung effort simulator controlled the lung while a pressure gauge was used to measure the pressures that were generated
- The device was set to 10 cmH_2O for testing because that is the most typical P_{mus}
- Pressures were measured for lung compliances from 10 to 100 mL/cmH_2O at 10 mL/cmH_2O intervals
- Sample size calculations (n=30) were performed to ensure a statistically significant result could be attained

RESULTS

The device was unsuccessful at reliably producing a P_{mus} of 10 cmH_2O due to the standard deviation being greater than the desired +/- 1 cmH_2O

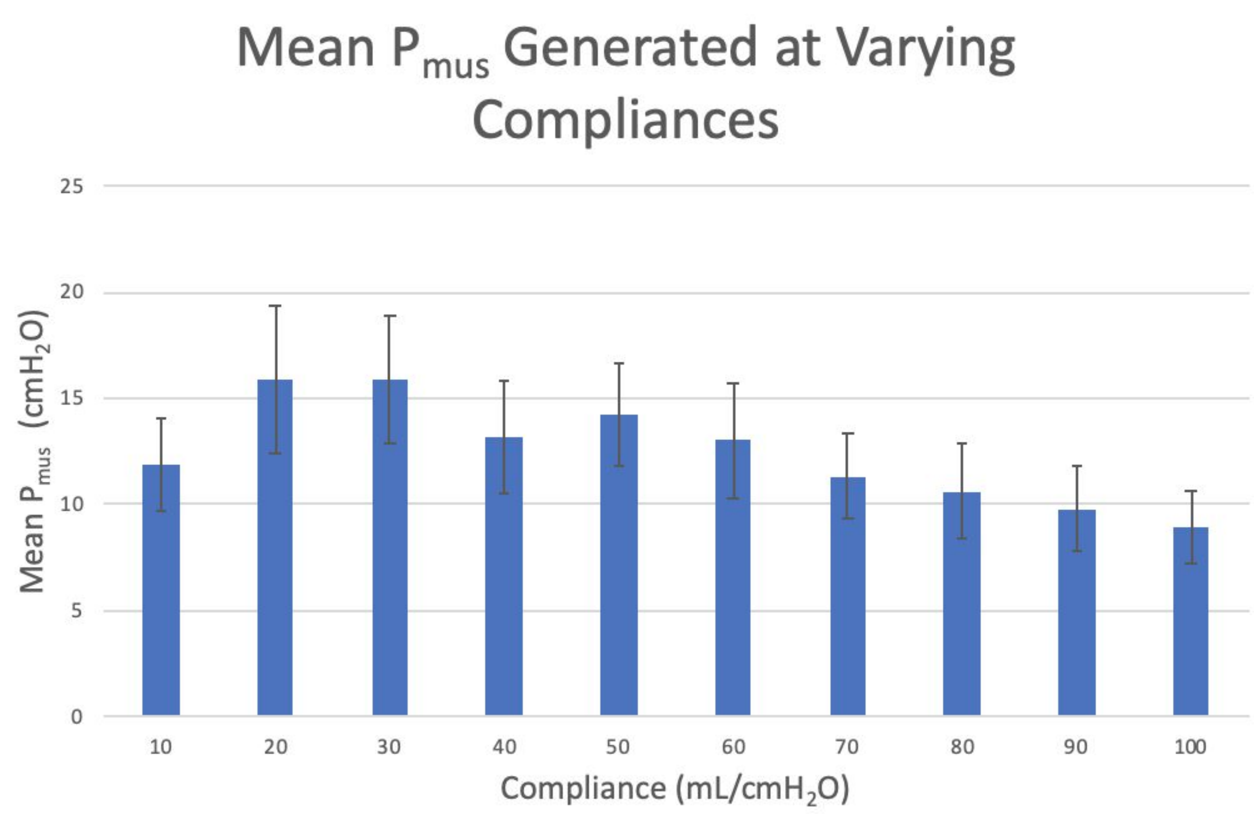

Figure 4. A graph showing how the mean P_{mus} generated by the device varied with the compliance the device was set to. The desired pressure was 10 cmH_2O

DISCUSSION

- System and simulink driver were operationally functional but generated inaccurate results. More work needs to be done to meet the design criteria.
- Sources of error:
  - Calibration that was done to correlate the force needed by the motor to the pressure produced in the lung. The process was inherently inaccurate due to human error.
  - Pressure gauge that was used only samples every 0.5 seconds, meaning the group could have taken inaccurate measurements.
- Testing was performed only for a P_{mus} of 10 cmH_2O due to the time constraints of the project. A more complete testing protocol would have included other pressure values.
- Initial pressure during testing in the lung would fluctuate even when at rest, partially because the motor supplied a resting torque. The team also suspects there may be an issue with the MITL.

FUTURE WORK

DESIGN ALTERATIONS

- Improve the tethering system so the connection rope does not slip on the rotor at all
- Calibrate the device so the resting torque of the motor is accounted for, and there is no pressure in the lung when a breath does not occur

EXPANDED TESTING

- Perform more calibration tests so Simulink can better correlate motor torque to P_{mus}
- Use a manometer that can take measurements faster than every .5 seconds since each breath lasts 1 second
- Verify the lung is airtight and does not leak

ACKNOWLEDGMENTS

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