Development of an Automated System Controller to Enable Suborbital Flight Evaluation of a Surgical System for Reduced Gravity

T Roussel[1], S Shacklette[1], C Jones[1], B Barrow[1], E Sutton[1], K Sharp[1], G Pantalos[1]
[1]Univ. of Louisville, Louisville, KY, tjrous02@louisville.edu, (502) 852-1528

Introduction. During human travel beyond low Earth orbit, a bleeding wound could easily and quickly compromise astronaut health, irreversibly contaminate the spacecraft, and jeopardize mission success. New technology will be essential to provide surgical treatment in reduced gravity. Since 2013, our research group has been developing a surgical fluid management system (SFMS) that incorporates an aqueous immersion surgical dome (AISD) to provide reliable wound containment and access. The dome is a clear chamber affixed to the skin to isolate and contain a bleeding wound, followed by filling with an immersion fluid (e.g., saline) that cleanses the wound and clears the visual field for surgical treatment. To evaluate the SFMS/AISD configured as an *automated* suborbital payload exposed to microgravity, a custom control system was developed to provide flexible and adaptable control with precise timing for the sequence of pumps and valves used to fill and empty the system and to further evaluate performance via flow and pressure sensors and control a prototype multi-function surgical wand-like device (MFSD) that provides fluid suction and irrigation. An overview of the system that supported suborbital flight evaluation of the integrated SFMS/AISD on Virgin Galactic's SpaceShipTwo in May 2021 is presented.

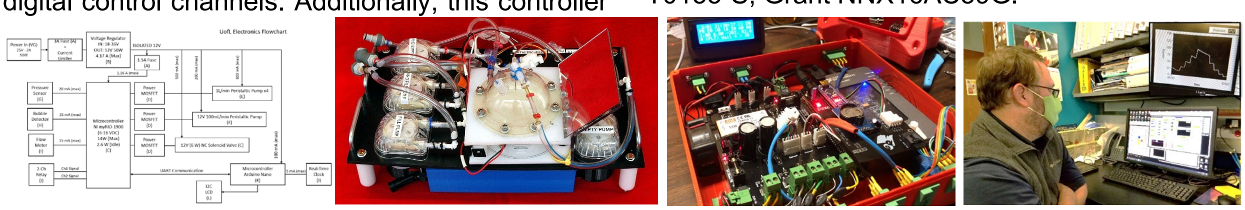
System Control Architecture. Per the flight provider, 24 volts of DC power was provided (50 W max) with no telemetry or remote enable or signaling. An isolated DC-DC voltage regulator (12V 50W 4.17A, SKM50B-12, Mean Well) was selected to provide regulated power to the system controller, sensors, and pumps. Filter stages and appropriate fusing were included to suppress noise and provide overcurrent protection. The control system uses an FPGA-enabled (Z-7010, Xilinx) embedded microcontroller (myRIO-1900, NI.com) with a high-resolution three-axis accelerometer (12-bit, +/- 8G), multiple analog inputs (12-bit, 500 kS/s), and 5V digital control channels. Additionally, this controller has a built-in Wi-Fi access point for wireless programming and monitoring.

Custom Electronics. A custom circuit (Altium Designer V20) was created, and high-current MOSFETs (NTD3055L104) were used to enable fluid control during fill, empty, suction, irrigation, and purge stages via 1L/min peristaltic pumps (MPP-12-1500). Inrush current limiters (SL08, Ametherm) were used to suppress motor current when enabling the 12V DC pumps. The PCB also contained inputs for three sensors to measure dome pressure (PendoTech; calibrated against physiological ranges, up to ~100 mmHg), in-line flow rate (up to 1L/min), and an optical fluid/air sensor (OCB350L250Z, TT Electronics) to enable automation of dome filling. A daughterboard PCB equipped with an Arduino Nano and real-time clock enabled serial UART communication to the myRIO. A 20x4 character display was used to provide visual monitoring of the various system control points during system operation. A pair of SPST 5V relays were used to control dome and canopy lighting.

Software. LabVIEW (V2020, NI.com) was used to develop a real-time state machine and sequencer that operated manually via GUI or in fully automated mode. A custom algorithm was developed to detect a sustained 2-sec < 0.05 g condition that triggered the 32-step sequence. All digital control point on/off timing, as well as acceleration, pressure, and flow signals were recorded on a USB flash drive.

Results. The automated experiment was triggered successfully after the system entered microgravity. The sequence, which included several stages of fluid manipulation and lighting control for visualization of MFSD functionality, completed in 166 seconds. Pressure data suggests more fluid volume will be needed to create internal dome pressures large enough to stop an arterial bleed.

Acknowledgement. This work was sponsored by the NASA Flight Opportunities program as payload T0155-S, Grant NNX16AC59G.



Figures: System schematic, AISD/SFMS experiment, Controller Internals, Software GUI evaluation