National Aeronautics and Space Administration

Miniaturized Isobaric Gas-Tight Sampler (MinIGT) for Biosignatures and Life Detection on Ocean Worlds

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Objective

The objective of this R&TD was to miniaturize an existing full ocean depth isobaric gas-tight sampler by a factor of 3 in size, weight, and power. We proposed to accomplish this miniaturization through the design of pressure tolerant electronics, which function in an oil flooded housing at pressures in excess of 100MPa. This allows for a small and lightweight housing that doesn't need thick walls to withstand high pressure, as the electronic chips can withstand the pressure directly. This work built upon the success of a previous R&TD, which validated the use of several key components at full ocean depth (an ARM Cortex M4 microprocessor and RS232 transceiver). We aimed to validate the use of a motor driver, thermocouple amplifier, power regulator, and current sensor. In addition to shrinking the electronics and actuator, the fluidic unit was miniaturized for a more modest but functional sampling volume.

Background

Deep sea hot springs (hydrothermal vents) are among Earth's most technically challenging environments from which to obtain scientific samples, reaching conditions up to 400°C and 50 MPa. Sampling and chemical analyses of these geologic fluids have transformed our understanding of crust-ocean heat/matter exchange, extreme microbial life on Earth, and possibilities for life's emergence (and sustenance) at seafloor hot springs on solar system ocean worlds (e.g., Enceladus and Europa). Current state-of-the-art technologies such as the Isobaric Gas-Tight (IGT) samplers designed at Woods Hole Oceanographic Institution (WHOI), and operated by WHOI and the University of Bergen (UiB), are heavy (~15kg), complex, and useable only by large (>2000kg) modern submersibles. In the last 3 years, our cross-institution team has shrunk mass and volume for state-of-the art autonomous submersibles by 2 orders of magnitude, first with Orpheus (300kg, WHOI+JPL) and then with MiniDeepSub (30kg, Spont. RTD at JPL+WHOI) by developing pressure tolerant electronics. Existing gas-tight fluid sampler designs must be miniaturized to enable detection of life and life-supporting gases (e.g. H_2, CH_4) at the scale of space-flight worthy submersibles.

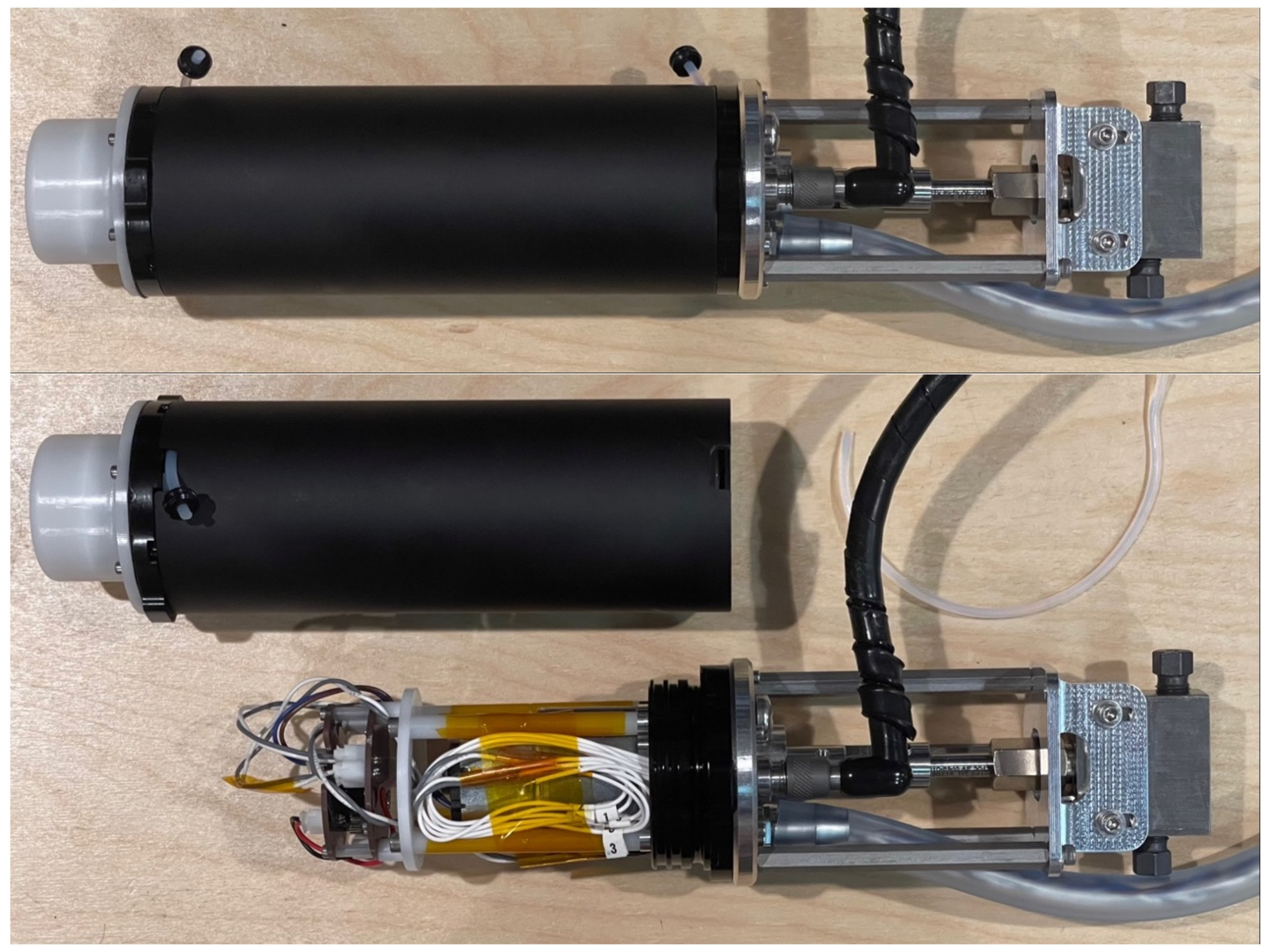
Approach and Results

Several parallel efforts were conducted: 1) redesign of fluidics unit for smaller sampling volume, 2) redesign of oil flooded valve/actuator assembly, 3) design of pressure tolerant electronics, and 4) software for control and communication.

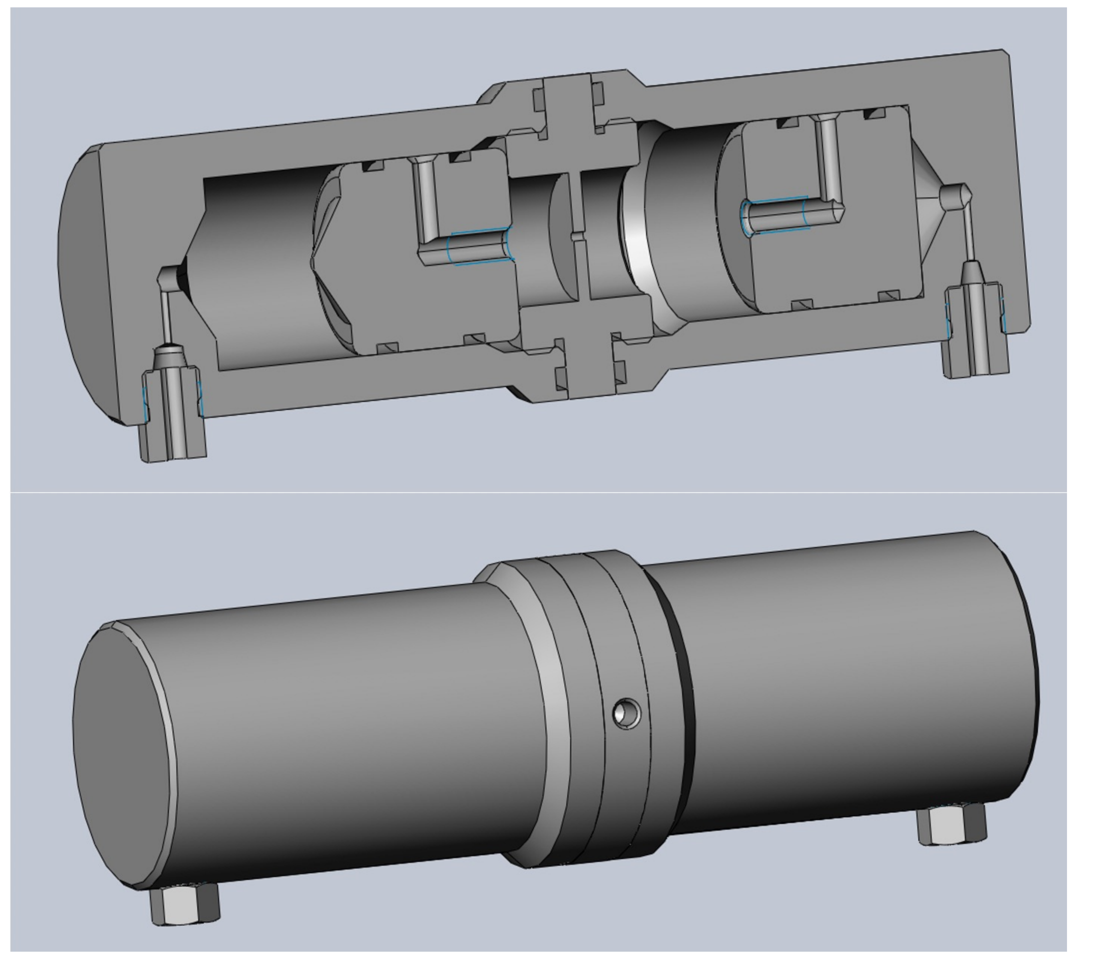
The new fluidics design was undertaken as a joint effort between JPL and WHOI/UIB. To miniaturize the design, an expensive valve was removed in favor of a machined pinhole. We also shrunk the overall sampler pistons and cylinder for a final sampler volume of 16.2 cc (from ~160cc). Machining challenges forced us to fabricate this unit out of Stainless Steel instead of Titanium, which is fine for gases like DIC and CH4. We may coat a future unit with tantalum to withstand reactive species that are problematic with SS (highly acidic, H2-rich fluids). This portion of the unit has not been delivered to JPL, but will weigh 1.75kg.
This assembly actuates a valve that requires three revolutions and 11 N-m of torque to achieve a tight seal. The previous unit used an actuator capable of running at 7.8 rpm at 12V with 12 N-m intermittent torque at 0.82 A (9.8 W). The motor + gearbox + output bearing weighed 400g. The new actuator sacrifices sampling speed for size and mass, with a 140g unit generating 12 N-m torque and running at 0.5rpm, but consuming only 0.6 W. This results in a 5% reduction in energy consumption, a 65% mass reduction, and a 6 minute sampling time to fully open the valve (up from 23 seconds). The sampling time is not ideal, but still functional. This new unit weighs ~3 kg.
The electronics were chosen to either substitute or exclude pressure intolerant devices. The major points are: substitution of multilayer ceramic capacitors for electrolytics (which burst under pressure), no crystal oscillators, no LED's, no MEMS. We are building a library of parts that have survived testing over 3 cycles to 110MPa and a fourth sustained hold for 13 hours. We designed the sampler avionics to run a motor (up to 3A, 16V) with stall current detection for feedback on the valve state. The avionics also detect temperature at an iron-constantan thermocouple probe (using a dedicated amplifier) and a 30kOhm thermistor at the reference junction (using an analog to digital converter). A communication link is handled over UART through an RS232 transceiver, which makes the system less susceptible to noise (often important in the presence of electrically noisy vehicle thrusters).
The software is written in CircuitPython, which increases accessibility and convenience of debugging (programming is accomplished by loading a python script onto the 2MB of onboard flash memory over USB). A control loop running at 10 Hz samples the thermistor, thermocouple, and motor current. Command packages sent over UART can set current limits and motor speed, and request system state information. The onboard control loop detects stall events (nominally corresponding with valve opened or closed) and set register flags with relevant information. Stall detection also prevents damage to the system from user commands.

Significance/Benefits to JPL and NASA

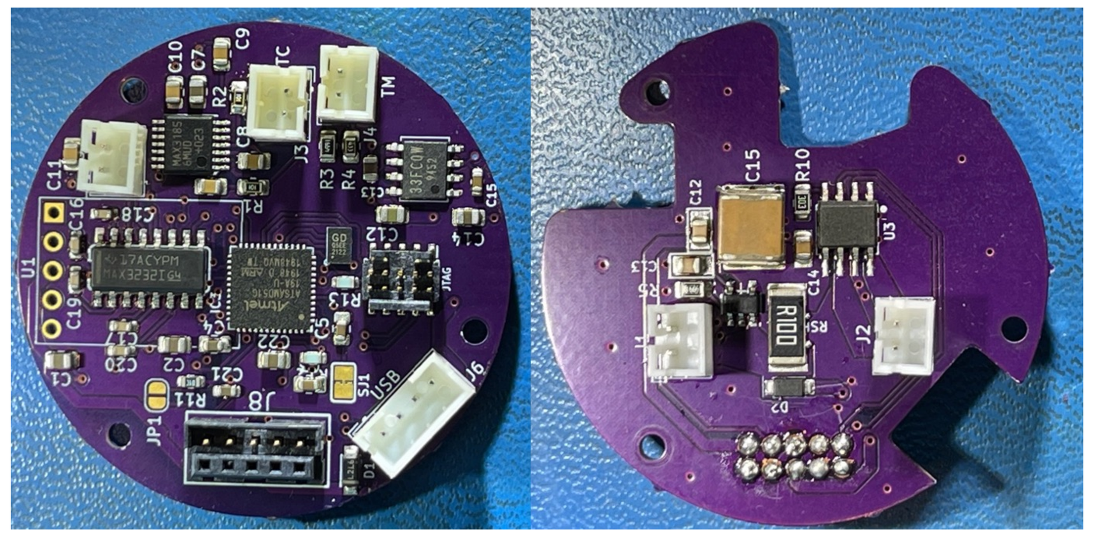
This sampler is ~1/3 the weight and volume of existing units, and can be mounted to a new miniaturized class of AUV such as MiniDeepSub (JPL R&TD Spont. '20). We are awaiting results of pressure testing at WHOI, but once fully qualified this design of a pressure tolerant avionics package with thermocouple amplifier, voltage regulator, motor actuation, and noise tolerant communication will provide new avenues for miniaturization of future deep ocean instruments for use on ocean worlds (Enceladus and Europa).



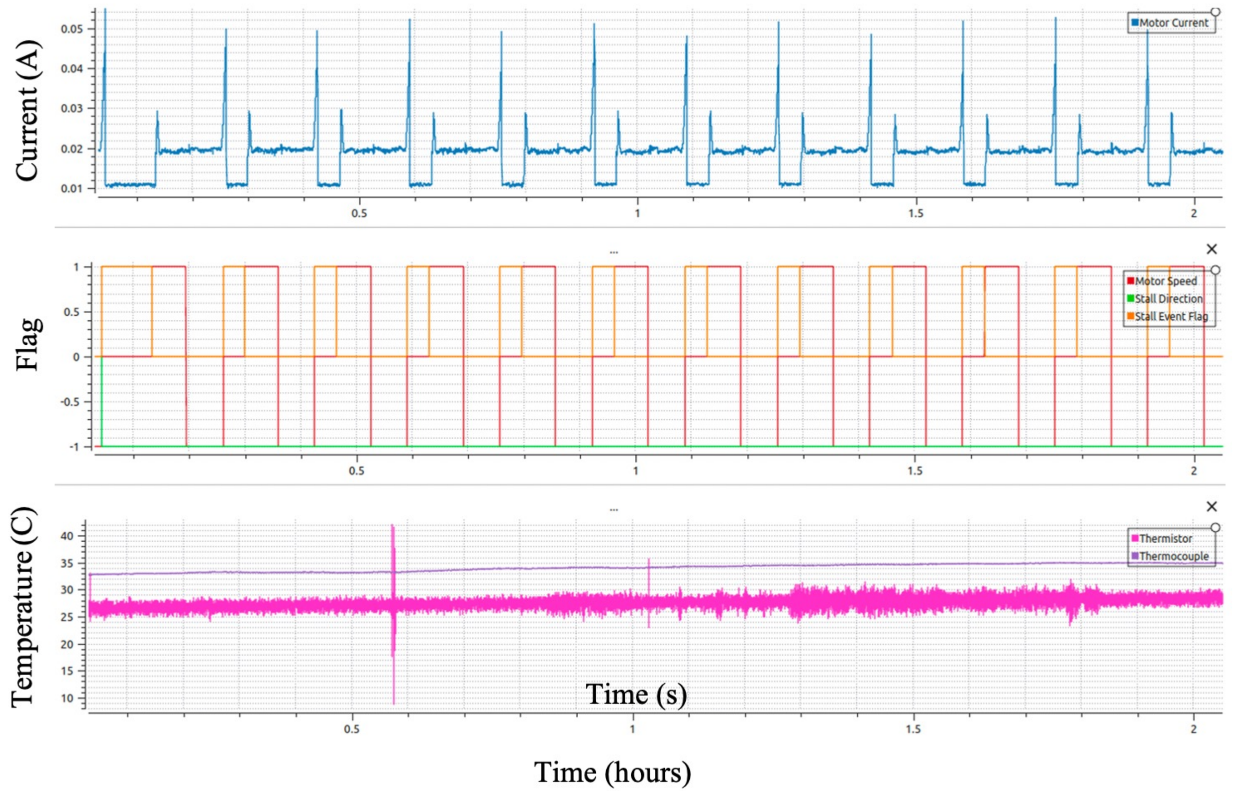
Assembled/Disassembled oil-flooded valve switching housing (contains actuator and avionics, shown sans oil)



Sampler unit. Fluid volume is on the left, gas volume is on the right.



Main avionics board layer on left (containing a voltage regulator, thermocouple amplifier, and RS232 transceiver), and motor driver electronics board layer on right (containing current sensor and motor driver)



This is a plot of 11 opening/closing cycles for the actuator turning the Parker fluidic valve. Stall events are detected at .05A and the motor is automatically stopped. Temperature across the trial is recorded as well (probe at room temp)

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