Evaluation of a Wearable CO2 Sensor

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The CO2 Problem

Exposure to elevated CO2 levels causes health problems

- CO2 can cause increased blood pressure, discomfort, dizziness, lethargy, and far more severe symptoms at increasing concentrations.
- ISS crewmembers have reported symptoms associated with high CO2 exposure at concentrations below the Spacecraft Maximum Allowable Concentration of 0.7%.
- Long term exposure to elevated CO2 levels may contribute to increased intracranial pressure, vision impairment, and decreased decision-making capabilities.

Monitoring CO2 in spacecraft is difficult

- Lack of natural convention limits air circulation and mixing
- CO2 readings at fixed sensors may not be representative of other locations
- Crew group activities (e.g. meals, public events) are of particular concern

Physiological impact of CO2 in spacecraft is not completely understood

- How do human adaptations to space affect sensitivity to CO2?
- How does CO2 influence intracranial pressure and vision impairment?
- How do individual differences affect susceptibility to elevated CO2?

The Foundational Question

What CO2 levels are ISS crewmembers actually experiencing?

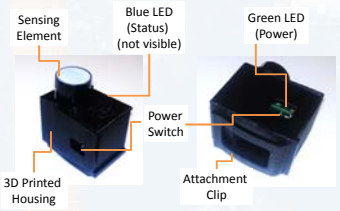
Answering this question is the first step towards answering many important questions:

- **Human Research:** What is the correlation between CO2 exposure and physiological/behavioral symptoms?
- **Operations:** What is the crew's CO2 exposure right now? How can ISS systems be most efficiently used?
- **Engineering:** Does crew exposure match environmental model predictions? How can the model be updated? How can new system requirements be met?
- **Spacecraft Designers:** What is an appropriate target for CO2 concentrations on future spacecraft?

The Wearable CO2 Sensor

The Wearable Electronics Application and Research (WEAR) Lab at JSC has developed a Wearable CO2 Sensor that captures and wirelessly records CO2 concentrations near the wearer over long duration.

Mass: 40.6 grams
Dimensions: 4.5 x 2.9 x 5.2cm
Sensing Rate: 1 Hz (adjustable)
Battery Life: Approx. 10 hours (depending on sampling rate)
Wireless Protocol: Bluetooth Low Energy



Evaluation

A human-factors evaluation was conducted using a prototype of the wearable CO2 sensor in order to examine attachment method, attachment placement, comfort, and level of distraction of the device.

Procedures

Six participants were instructed to attach the sensor on the upper half of their torso, completed three tasks while wearing the sensor, then removed the sensor and completed a usability survey. The tasks completed by participants included a large motion task (retrieving objects above head-height, retrieving objects at shoulder height, and retrieving objects on ground level), a moderate motion task (card sort at workstation), and minimal motion task (online search using a laptop).

Results

The majority of the participants attached the sensor to their collar or upper chest/shirt pocket, while some participants attached the sensor to the upper buttons or sleeves of their shirt. Results of the usability survey indicated that the prototype was comfortable and not distracting, however, it was not as easy to attach/remove as desired. Results of this study were used to redesign the sensor for evaluation during a NEEMO mission.

NEEMO Evaluation

The Wearable CO2 Sensor was evaluated on the NASA Extreme Environments Mission Operations (NEEMO) analog in 2014. NEEMO provided a flight-like operational environment, 60 feet underwater off the Florida Keys.

Research Aims

Primary

- Assess the comfort, usability, and operational impact of the Wearable CO2 Sensor.
- Identify where on their upper torso users prefer to attach the Wearable CO2 Sensor.

Secondary

- Evaluate the reliability of the Bluetooth Low Energy wireless communication hardware in an ISS-like RF environment.
- Assess the reliability of the CO2 sensing element in an operational environment.

Procedures

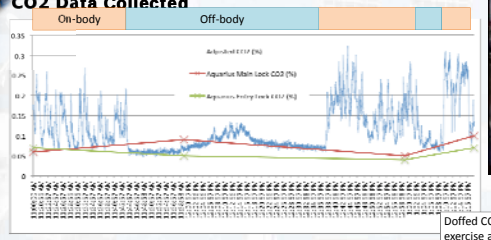
Four participants donned the Wearable CO2 Sensor for two sessions each, average 3.5 hours per session. With the exception of exercise and activities in a high humidity portion of the habitat, subjects wore the device during all other tasks.

User Feedback

- Easy to attach & remove
- Very comfortable
- Not at all distracting

"Very nice device. Small & easy to operate."

CO2 Data Collected



Doffed CO2 sensor captures CO2 increase due to crew exercise and is consistent with habitat ECLSS system hourly readings.

Findings

- The attachment method, mass, and dimensions were very well-received by users.
- The device was most frequently attached to the collar or shirt buttons
- Crew mentioned the device "disappeared" during other operational activities.
- Software bugs caused some wireless network dropouts, not the operational environment.
- The CO2 data readings never returned to ambient CO2 conditions because of direct exhalation onto the sensor.
- CO2 readings indicated good calibration and consistent readings when the crew was not wearing the device.

Continuing Development

Second Generation Improvements

Status: Hardware complete, finishing software development & housing

- Monitors CO2, temperature, humidity
- Compliant with standard Bluetooth Low Energy protocols
- Smaller form factor, rechargeable battery, longer battery life

Gathering requirements for ISS → Help Guide Generation 3!

- Targeting ISS: Parts selection, body attachment, network
- Targeting Data Users: Sampling rate, battery life, sensors
- Tell us what you need in the third generation!

References

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