An Affordable Autonomous 2U-Greenhouse for Plant Research in Low-Gravity Environments

Dominik Woiwode[†], **Jakob Marten**[‡], Justin Sondheim, Dörthe Behrens, Nils Wörz, Natalija Hohnjec, Helge Küster, Holger Blume

Leibniz University Hannover, [†]Institute for Information Processing, [‡]Institute of Microelectronic Systems

Motivation & Purpose

- 2U-Greenhouse for plant experiments in low gravity
- Low material costs (<500€) due to commercial of the shelf (COTS) parts
- Designed as part of the Überflieger2 contest for the investigating of root nodule symbiosis between *Medicago truncatula* and *Sinorhizobium meliloti* on the International Space Station (ISS) [1]

Setup of the Greenhouse

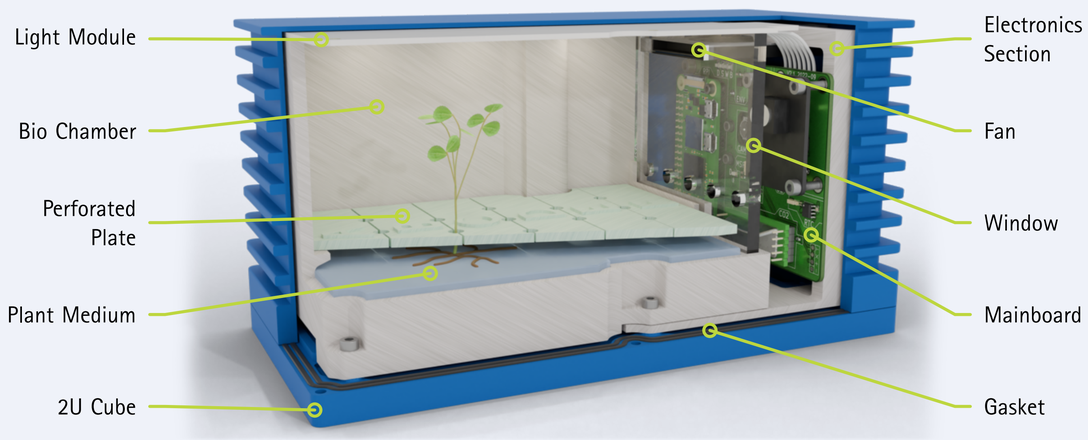

Figure 1: Setup of the greenhouse in a 2U cube.

- Two separate components (bio chamber, electronics section) in 2U cube
- 3D printed (SLA) autoclavable parts using bio-compatible resin
- $150 \times 94 \times 87\,\mathrm{mm}^3$ volume for plants and plant medium
- Fully autonomous operation with self-recoverable software design
- Perforated plates shade roots from excessive illumination
- Fan to accelerate the diffusion of produced gases necessary due to the lack of convection

Electronics

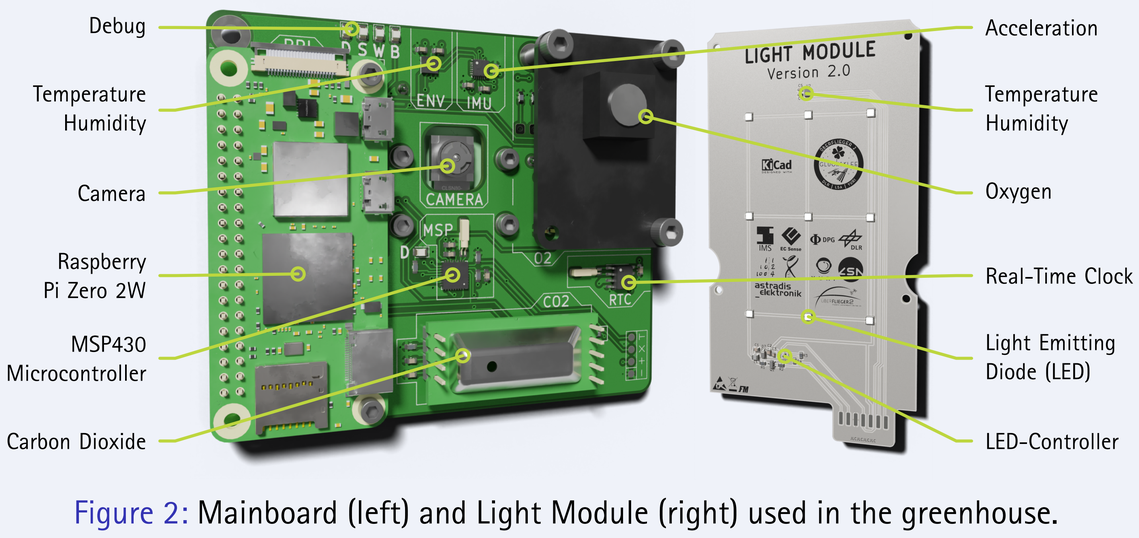

Figure 2: Mainboard (left) and Light Module (right) used in the greenhouse.

- Raspberry Pi Zero 2W as main processor with MSP430 microcontroller
- Different sensors for monitoring temperature, humidity, oxygen, carbon dioxide and acceleration; camera for image and video footage
- Communication via Ethernet-over-USB interface to main payload
- Designed for shared atmosphere for simpler sensor placement
- Real-time clock for timekeeping during (ground) operation and launch

[1] N. Wörz, J. Sondheim, D. Behrens, D. Woiwode, D. Rudy, and Team Glücksklee, 'Pflanzenforschung an Bord der ISS', BIOspektrum, vol. 29, no. 5, pp. 557–557, Sep. 2023, https://doi.org/10.1007/s12268-023-1972-1

Software

- Main purpose: control light and fan in regular cycles; secondary purpose: gather sensor data and camera footage
- Implemented using Python 3 on Raspberry Pi OS
- Independent modules that stay functional if another fails
- Built-in failure recovery with MSP430: If a heartbeat signal is not received within one minute, the microcontroller attempts to restart the Raspberry Pi Zero 2W and therefore the software

Mission Findings

Figure 3: View from inside the experiment.

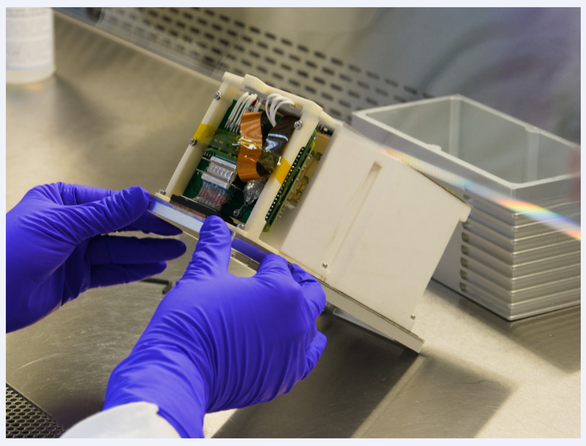

Figure 4: Experiment during assembly in sterile bench.

- Was actively operated for 22 days during SPX-27 mission on the ISS
- As expected, the high humidity caused problems for some sensors
- Hardware and software continued to run successfully, maintaining the fan and light cycles despite sensor failures
- Loss of data during launch operation due to misconfiguration, causing the memory to fill up
- Average power consumption: 900 mW (day), 780 mW (night)
- Gas values show an active photosynthesis cycle which lines up with day-night-cycle

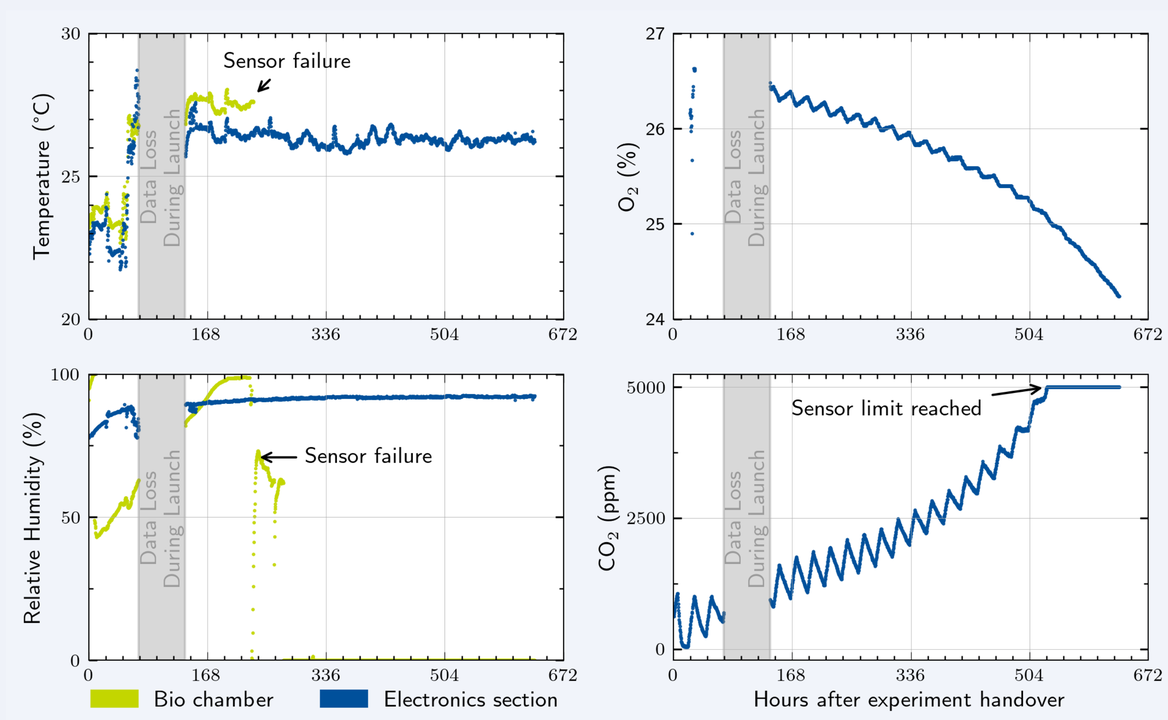

Figure 5: Sensor measurements from selected sensors during SPX-27 mission on ISS.

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