A mobile sensor package for real-time greenhouse monitoring using open-source hardware

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Abstract

Increased demand for precision agriculture is reflected by a global rise in greenhouse food production. To maximize crop efficiency and yield, commercial greenhouses require live monitoring of growth conditions. Recent advances in open-source hardware allow for environmental sensing with the potential to rival lab-grade equipment at a fraction of the cost. This study introduces a high-resolution sensor package that costs less than $400. Consisting of microcontrollers and small open-source hardware, the sensor package can be deployed on the HyperRail, a modular conveyance system developed in Oregon State University's OPEnS Lab. The system can then provide data from multiple sensing locations at the cost of a single package. Sensor data, including CO2, temperature, relative humidity, luminosity and dust/pollen, is saved to a microSD card as the HyperRail-mounted package travels throughout the greenhouse. A wireless GFSK nRF connection to a network hub allows the broadcast of a live stream of environmental conditions online. CO2 monitoring efforts are especially relevant to greenhouse management as artificially elevated levels can significantly increase plant growth. Results from calibration in the lab show that the K30 CO2 sensor ($85) can be calibrated to be accurate within less than 10 ppm of industry standard equipment costing up to $10,000. Our sensor package's instructions, code, wiring, and 3D-printed enclosures are openly-published on GitHub. Addition of an RFID tag soil moisture sensing system is anticipated. Actuators may also be integrated in the future, allowing the system to automatically adjust greenhouse controls (i.e. CO2, water) in response to sensor readings. The affordability of this package can make precision agriculture more accessible in developing countries where conventional monitoring systems are not feasible. Efficient use of resources and the ability to adapt to local challenges with input from the open-source community has the potential to improve global crop yield.

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eGreenhouse
A Mobile Sensor Package for Real-Time Greenhouse Monitoring

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ABSTRACT

Increased demand for precision agriculture is reflected by a global rise in greenhouse food production. To maximize crop efficiency and yield, commercial greenhouses require live monitoring of growth conditions. Recent advances in open-source hardware allow for environmental sensing with the potential to rival lab-grade equipment at a fraction of the cost. This study introduces a high-resolution sensor package that costs less than $400. Consisting of microcontrollers and small open-source hardware, the sensor package can be deployed on the HyperRail, a modular conveyance system developed in Oregon State University's OPEnS Lab. The system can then provide data from multiple sensing locations at the cost of a single package. Sensor data, including CO_2, temperature, relative humidity, luminosity and air quality, is saved to a microSD card. A wireless GFSK nRF connection to a network hub allows the broadcast of a live stream of these data online. Results from calibration in the lab show that the Senseair K30 CO_2 sensor ($85) can be calibrated within 10 ppm of industry standard equipment costing thousands of dollars. The flexibility and affordability of this package can make precision agriculture more accessible in developing countries where conventional monitoring systems are not feasible.

OPEN-SOURCE HARDWARE

- Programmed in C++ with the Adafruit Feather microcontroller at its core, similar to the Arduino Uno but with higher data transfer capacity at lower power and a smaller footprint.
- Sensors soldered directly into a printable circuit board (PCB) designed in EAGLE CAD (Figure 2)
- A wireless charging transmitter and receiver coupled with the PowerBoost 1000C step-up and charging module
- A custom 3D-printed enclosure designed in Fusion 360 for water-resistance and HyperRail attachment.
- Wireless data sent via open sound control (OSC) bundles between each transmission node using 2.4-GHz GSFK nRF

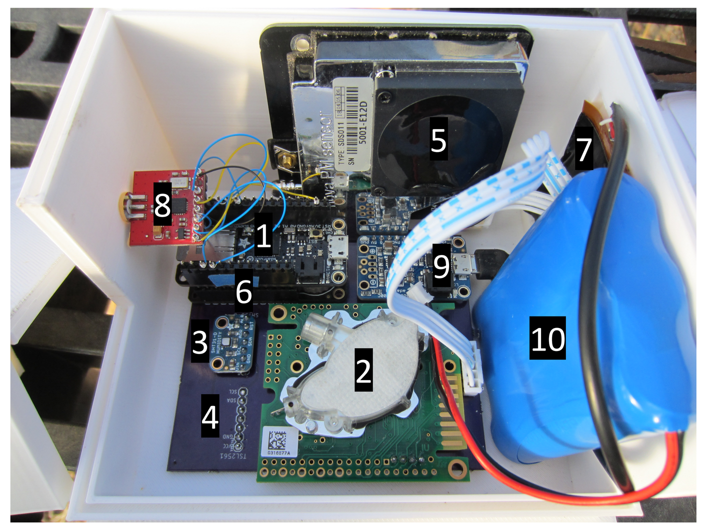


Figure 1: eGreenhouse Hardware

1. **Processor:** Adafruit Feather Adalogger
2. **CO_2:** Senseair K30 (30 ppm ±3% without calibration)
3. **Temp/RH:** Adafruit SHT31-D (± 3˚C, ±2% RH)
4. **Lux:** Adafruit TSL2561 (0.1 – 40,000)
5. **Particulate Matter:** Nova PM SDS011 (0.3 µ g/m³)
6. **RTC:** Adafruit DS3231 Featherwing
7. **Wireless Charging:** Adafruit Universal Qi
8. **Transmission:** Nordic Semiconductor 2.4 GHz nRF
9. **Power Management:** Adafruit PowerBoost 1000C
10. **Battery:** Adafruit 6600 mAh lithium ion battery pack
11. **Data:** Adalogger, microSD, PushingBox, Google Sheets

FROM GREENHOUSE TO GOOGLE

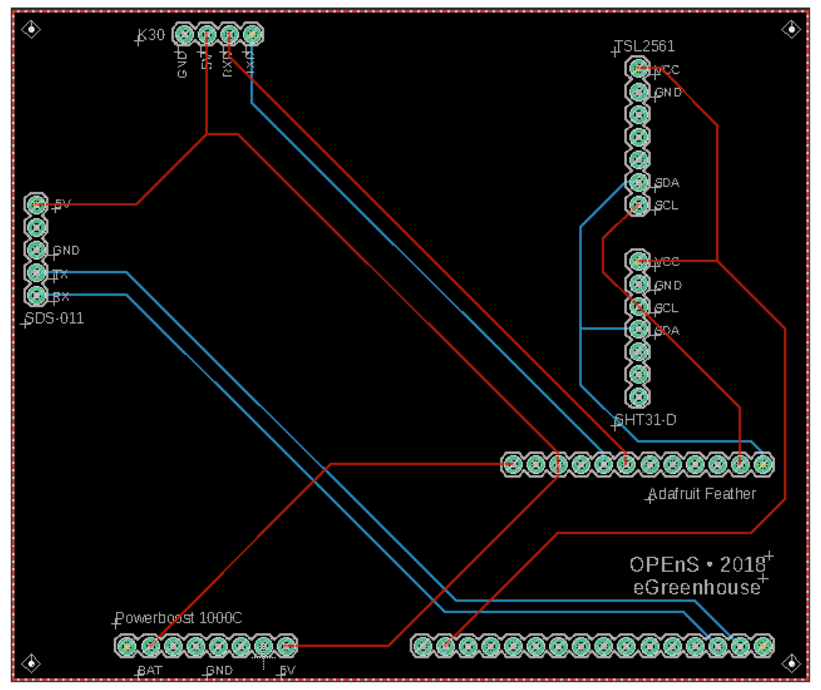


Figure 2: Printable circuit board at the core of the sensor package pictured in figure 5 (right), eliminating cumbersome wires and improving reliability

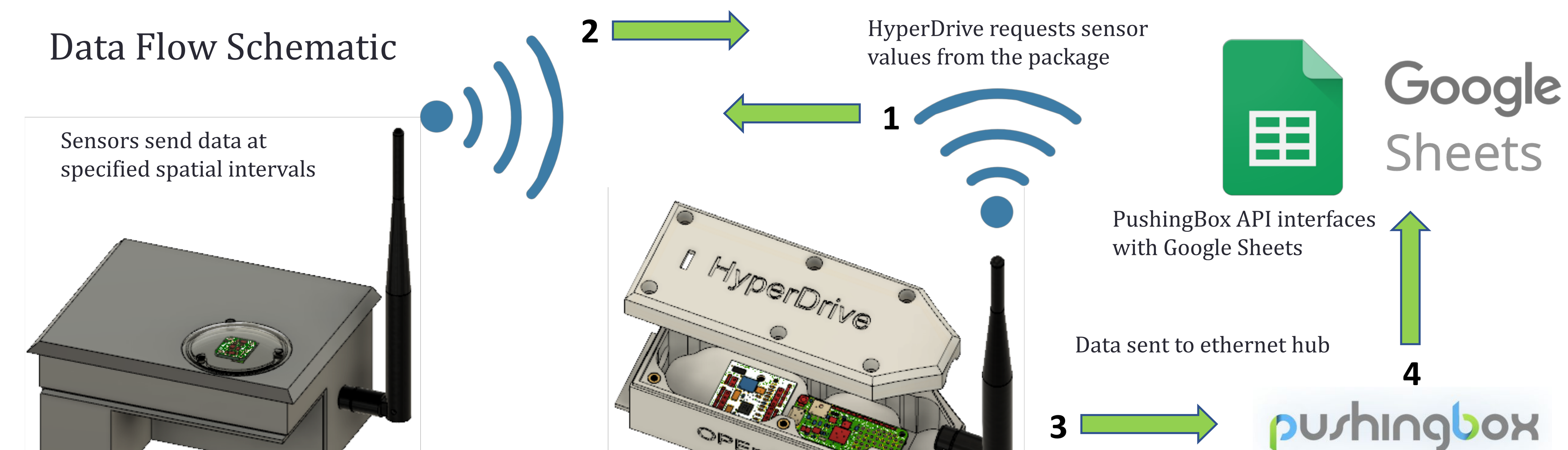
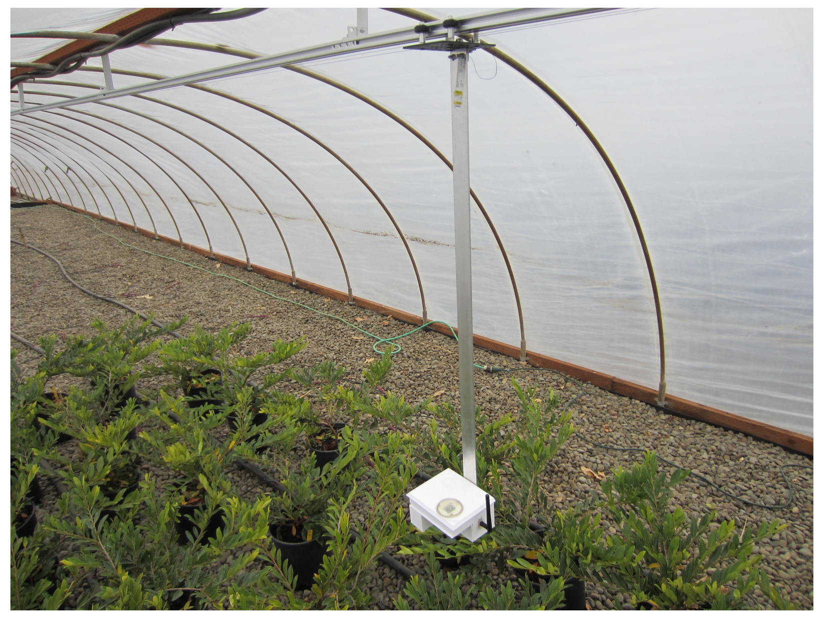


Figure 5: Data transmission schematic from multiple positions in the greenhouse to Google Sheets in real time

DEPLOYMENT



	A	B	C	D	E	F	G	H
1	Date	Time	deviceID	CO2	Lux	Temp	RH	Particle
2	August 3, 2018	11:05:32 AM PDT	TestDevice42	510	24	26	48	2
3	August 3, 2018	11:08:04 AM PDT	TestDevice42	504	24	26	48	2
4	August 3, 2018	11:08:20 AM PDT	TestDevice42	505	24	26	48	2
5	August 3, 2018	11:08:36 AM PDT	TestDevice42	506	24	26	48	1
6	August 3, 2018	11:08:53 AM PDT	TestDevice42	505	24	26	48	1
7	August 3, 2018	11:09:08 AM PDT	TestDevice42	504	24	26	48	2
8	August 3, 2018	11:09:24 AM PDT	TestDevice42	504	24	26	48	3
9	August 3, 2018	11:09:40 AM PDT	TestDevice42	503	24	26	48	2
10	August 3, 2018	11:09:56 AM PDT	TestDevice42	503	24	26	48	2
11	August 3, 2018	11:10:12 AM PDT	TestDevice42	503	40	26	48	2
12	August 3, 2018	11:10:28 AM PDT	TestDevice42	503	40	26	48	2
13	August 3, 2018	11:10:44 AM PDT	TestDevice42	503	6	26	48	1
14	August 3, 2018	11:11:48 AM PDT	TestDevice42	834	71	26	47	2
15	August 3, 2018	11:12:04 AM PDT	TestDevice42	624	86	26	47	4
16	August 3, 2018	11:12:20 AM PDT	TestDevice42	552	71	26	47	4
17	August 8, 2018	3:10:49 PM PDT	TestDevice42	564	136	26	44	6
18	August 8, 2018	3:11:06 PM PDT	TestDevice42	564	136	26	44	6
19	August 8, 2018	3:11:14 PM PDT	TestDevice42	564	121	26	44	7
20	August 8, 2018	3:11:32 PM PDT	TestDevice42	564	121	26	44	7
21	August 8, 2018	3:11:41 PM PDT	TestDevice42	563	136	26	44	7
22	August 8, 2018	3:11:59 PM PDT	TestDevice42	563	136	26	44	6
23	August 8, 2018	3:12:07 PM PDT	TestDevice42	563	151	26	44	6
24	August 8, 2018	3:12:25 PM PDT	TestDevice42	563	136	26	44	6
25	August 8, 2018	3:12:33 PM PDT	TestDevice42	563	121	26	44	6
26	August 8, 2018	3:12:51 PM PDT	TestDevice42	562	136	26	44	6
27	August 8, 2018	3:12:59 PM PDT	TestDevice42	562	136	26	44	7
28	August 8, 2018	3:15:11 PM PDT	TestDevice42	558	121	26	44	6
29	August 8, 2018	3:15:29 PM PDT	TestDevice42	558	136	26	44	6
30	August 8, 2018	3:15:37 PM PDT	TestDevice42	558	136	26	44	6
31	August 8, 2018	3:15:55 PM PDT	TestDevice42	558	121	26	44	7

Figure 3: Deployment of eGreenhouse and HyperRail at NWREC (left). Test data showing data from the field sent to Google Sheets across 3 nRF nodes and the PushingBox API (right).

Preliminary testing from full-scale deployment on a 25-meter HyperRail at the North Willamette Research and Extension Center (NWREC) shows promising results. Data has been successfully sent via nRF across three nodes spanning over 100 meters. The HyperDrive hub drives the sensor package along the rail and sends requests for specified sensors at any spatial interval. Upon receipt of these data, the hub sends OSC bundles across a field to a third node at the extension office with ethernet connectivity. The data is uploaded to Google Sheets using the PushingBox API.

The Google Sheets script can be updated from the C++ code to include any relevant columns such as position along the rail. Data can be viewed remotely and plots values in real time. Each data cycle takes under 5 seconds to complete. Up to 1000 data points can be pushed to the spreadsheet per day.

CALIBRATION

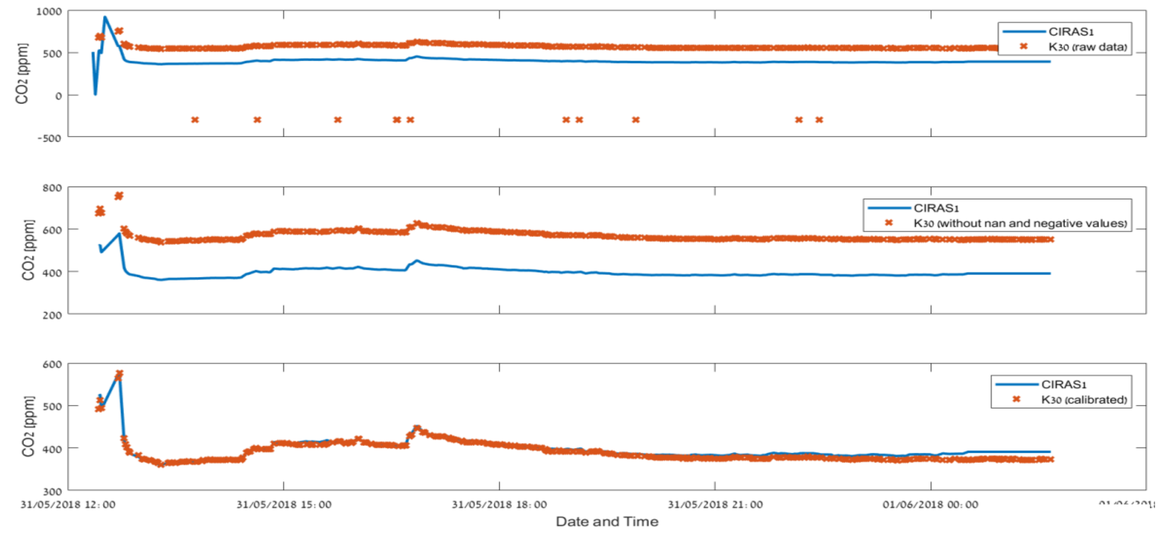


Figure 4: Senseair K30 ($85) calibrated with the Portable Photosynthesis Systems CIRAS1 standard lab gas analyzing equipment. Mean CO_2 levels were within 10 ppm after adjustment on average with R^2 = 0.94. Calibration performed and prepared by Elad Levintal at the Water Research Institute in Israel.

FUTURE RESEARCH

- **Full-scale deployment** is in progress. The sensor package is running every 15 minutes, saving locally to microSD while more robust and affordable nRF modules are explored.
- **Experiments capturing spatial variation of CO_2** planned for submission to a peer-reviewed open access journal with Levintal in early 2019.
- **Testing and validation** of the sensors have shown promising results. CO_2 is especially relevant in greenhouses, because optimal plant growth occurs around 1000 ppm while ambient levels are closer to 400 ppm. Greenhouse managers often add supplemental CO_2, heat and light at significant expense.
- **Future development** may include optical plant-stress monitoring and soil moisture. Actuators could also be integrated with the system to adjust greenhouse controls such as watering, heating/cooling and CO_2. The modular nature of the system allows for myriad arrangements of light-weight open-source sensors to support the goals of each unique deployment site.

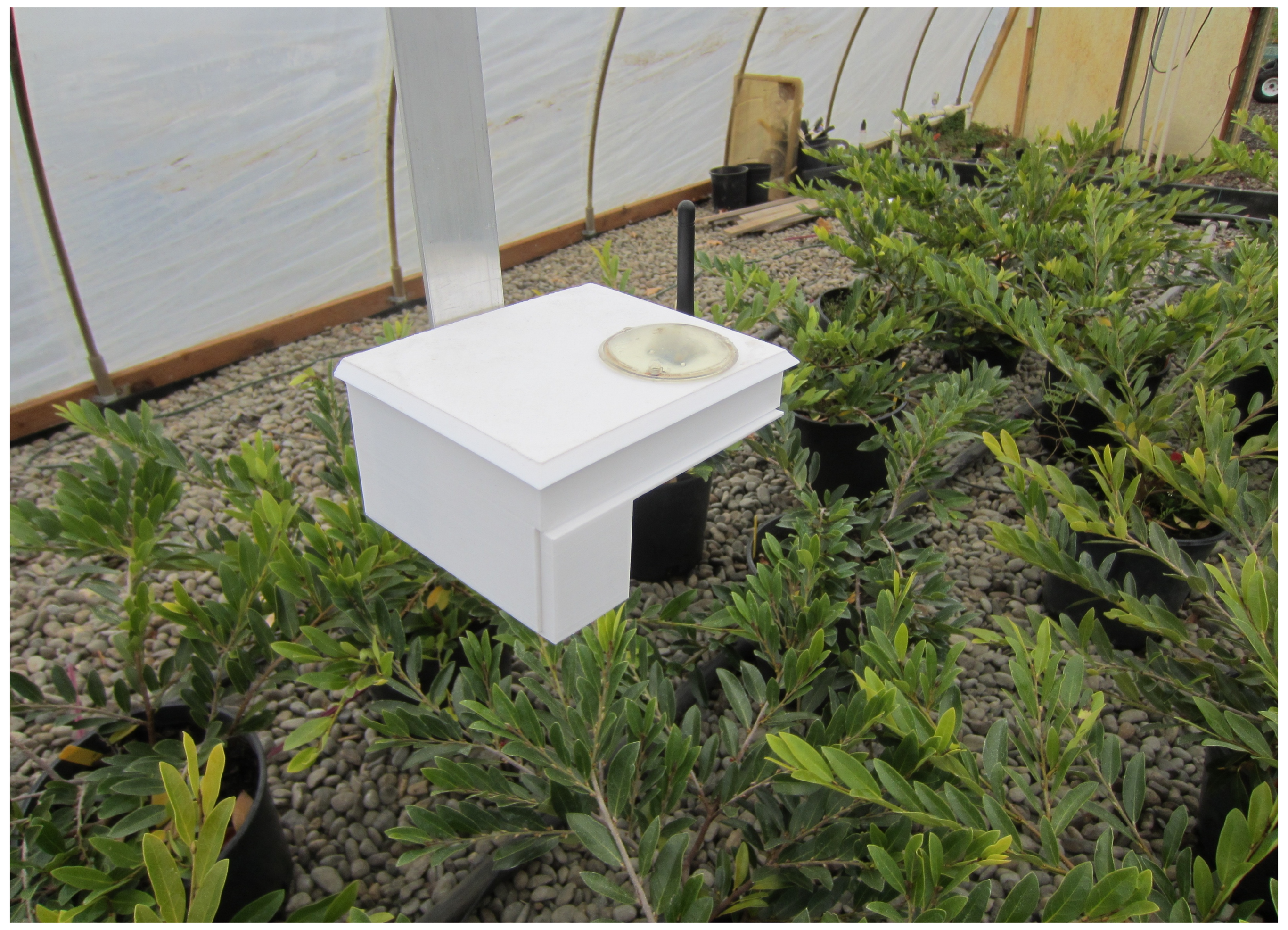


Figure 6: The sensor package mounted to the HyperRail at NWREC. The package is positioned near the plant canopy to capture CO_2. The clear dome on the enclosure is a water resistant resin-printed housing with a laser-cut cork seal for the TSL2561 lux sensor.

CONCLUSIONS

- **Calibration** shows the $80 K30 performs within 10 ppm of gas analyzers costing thousands of dollars
- **Preliminary testing** indicates the sensor package, wireless charging, and nRF transmission are robust and integrate successfully with the HyperRail.
- **Future potential** for expansion to include actuators to adjust greenhouse controls
- **Soil Moisture and NDVI** are promising additions to the eGreenhouse sensor suite. Low-cost RFID tag soil moisture sensors can be read from an OPEnS-Lab scanner integrated into the Loom ecosystem.

ACKNOWLEDGEMENTS

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Scan the QR code for all eGreenhouse code, tutorials, datasheets, PCB and 3D-printed enclosure files, libraries, and bill of materials.