Using 3D-Printers and Low-Cost Microcontroller Boards to Build Open-Source Environmental Instrumentation

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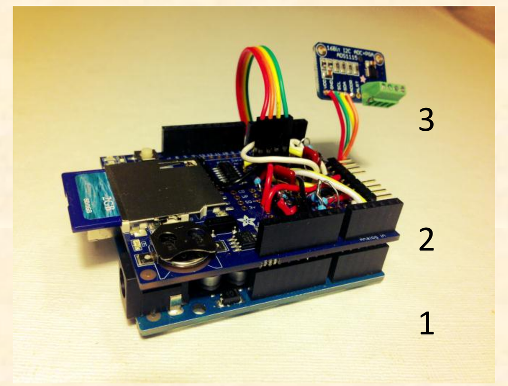
System Design

The objective of this project was to design, prototype, and test a research-grade weather station that is based on open-source hardware/software and off-the-shelf components. Some parts were fabricated using a 3D printer. The system measures all primary weather variables: air temperature, humidity, global irradiance, wind speed, wind direction, and precipitation. The Arduino-based datalogger calculates averages and other statistics then stores time-stamped data on an SD card.

Datalogger



1. Arduino Uno Microcontroller
2. Data Acquisition Shield with user-installed debounce circuits in the proto-area (Adafruit Industries)
3. 16-bit ADS1115 ADC breakout (Adafruit Industries)*

Power

- Power is provided by a 5W solar panel, charge controller, and and 12V, 7AH battery and a 5V switching regular.

Software

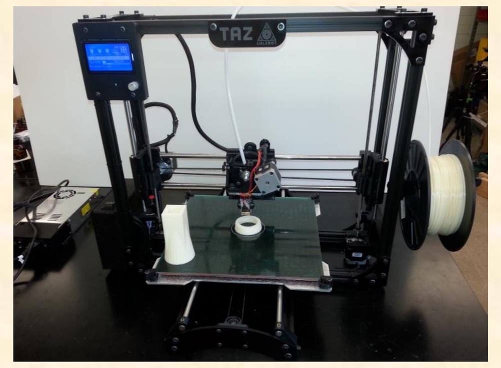
- Samples sensors every 5 seconds
- Calculates the wind vector and dew point temperature
- Stores time-stamped, 5-minute averages of all variables plus other statistics (e.g., max. wind gusts) on an SD card.

GitHub https://gist.github.com/jaymham/7792782

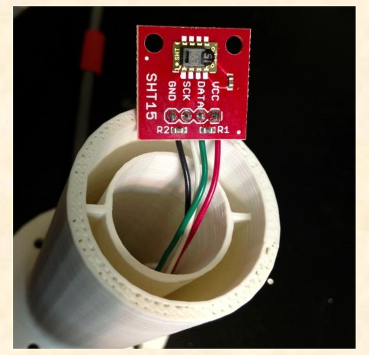
"Git" the Arduino Sketch/Code !

3D Printers

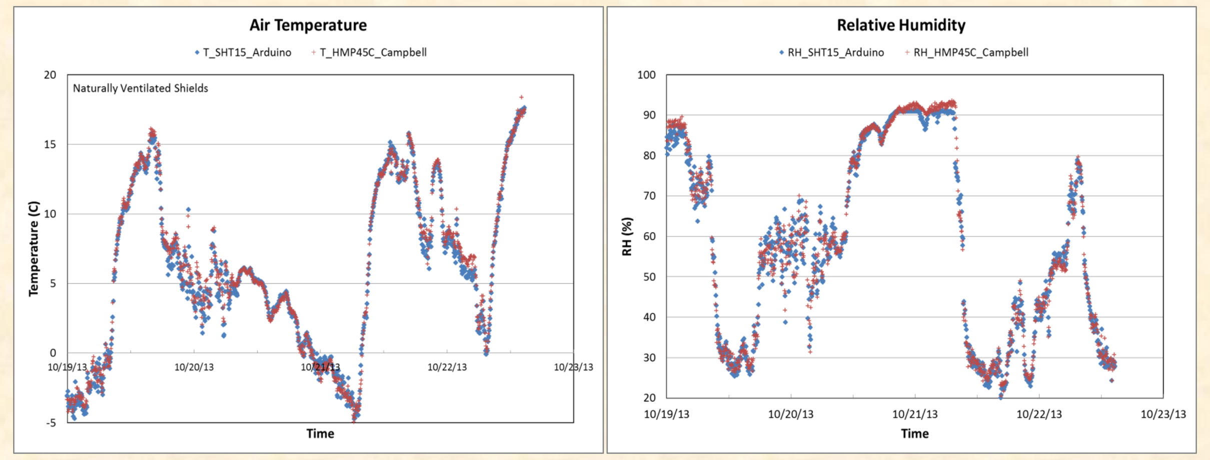
Lulzbot Taz 2.0, www.lulzbot.com/ Airwolf 3D, www.airwolf3d.com



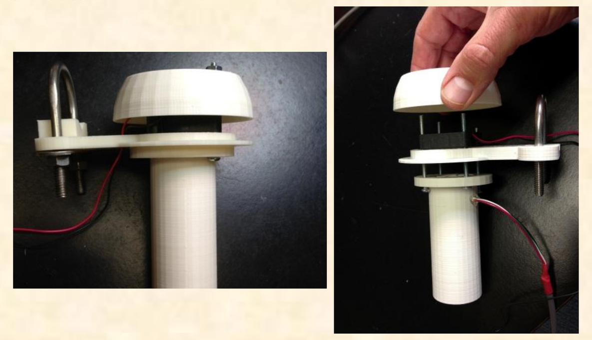
Temperature and RH



Two devices that showed promise for measuring temperature and humidity were: 1) the Sensirion SHT15 (vendor Sparkfun Electronics,) and 2) the innovative sensor technology HYT 271 (vendor Newark Electronics). Shown left is the SHT 15 being installed in the barrel of the 3D-printed aspirated shield (see below).



Comparison of the SHT15 sensor on the Arduino weather station to a nearby Vaisala HMP45C sensor on a station operated by the Department of Atmospheric Science, Colorado State University. Naturally ventilated shields were used on both stations.

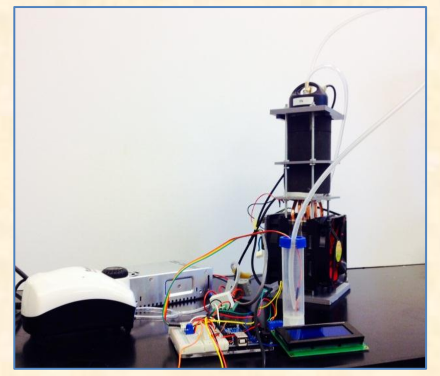


A "printable" fan-ventilated shield for improved temperature measurement was developed for the SHT15 sensor. A small 40mm DC fan provided aspiration rates near 4 m/s. The barrel of the shield is double walled to reduce radiation errors. This shield will be field tested in the summer of 2014.

Download the shield for 3D printing at http://www.thingiverse.com/thing:193569

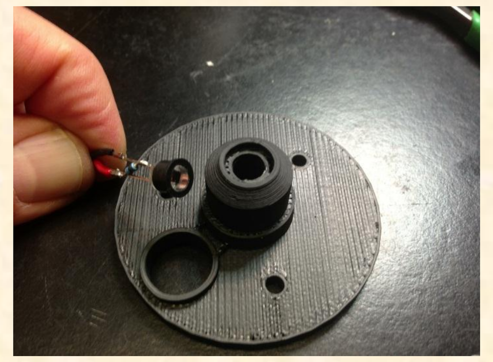
Dew Point Generator

An Arduino based dew-point generator was built for less than $150 using a water bottle, CPU heat exchanger, and other off-the-shelf components. Accuracy was verified using a General Eastern dew-point hygrometer.



Solar Radiation

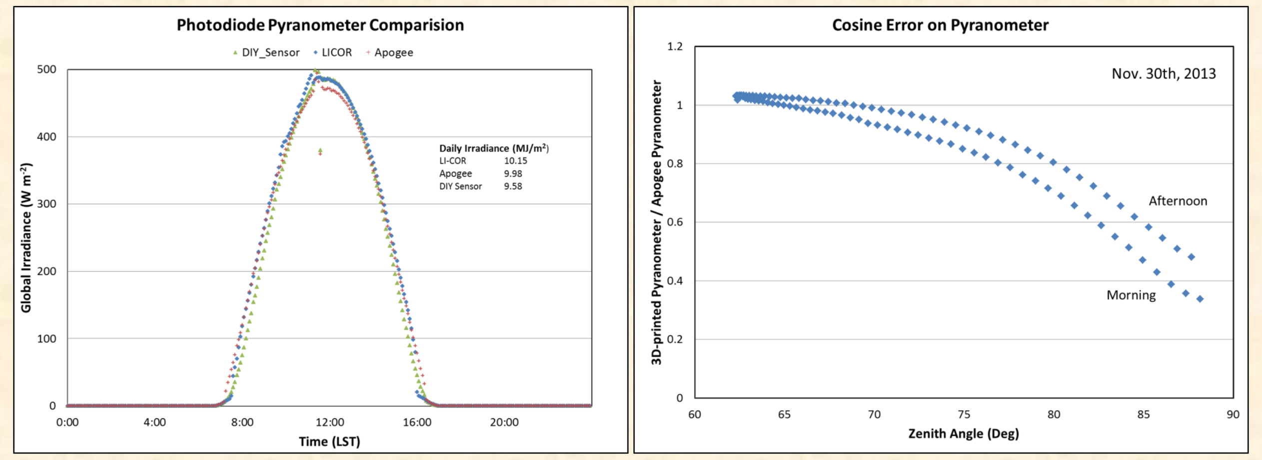
3D printed pyranometer. The sensor includes a 1mm-thick Teflon diffuser above the photodiode, bubble level, and mounting bracket.



Preparing to install the photodiode (Advanced Photonics, PDB-C139, $5) in the 3D printed pyranometer housing.

This photodiode approach was adapted from the DIY pyranometer described by David Brooks, http://www.instesre.org/construction/pyranometer/pyranometer.htm

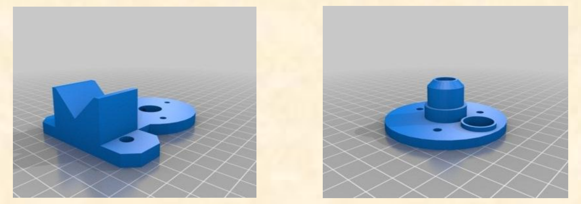
Download for 3D printing at http://www.thingiverse.com/thing:196191



Comparison of the 3D printed pyranometer connected to the Arduino logger to commercial instruments (model LI-200, Li-Cor, Lincoln, NE; model SP215, Apogee Instruments, Logan, Utah) monitored by a Campbell Scientific CR800 datalogger.

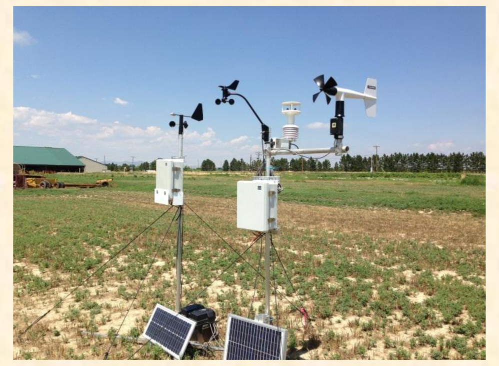
Pyranometer Results

- Calibration coefficients for the PDB-C139 photodiode (with a 470 ohm shunt resistor) and a 1-mm-thick teflon diffuser were typically between 3.3 and 3.6 Wm^{-2} per mV.
- The use of a low-cost 16-bit ADC with an I2C interface allowed the small voltage signals from the photodiode to be measured accurately with the Arduino.
- Some cosine and azimuth errors were observed at large zenith angles
- Next step: improve diffuser design to reduce cosine error and conduct more tests during spring and summer.
- Conclusion: This $5 pyranometer has adequate accuracy for many studies provided it is properly calibrated against a commercial standard.



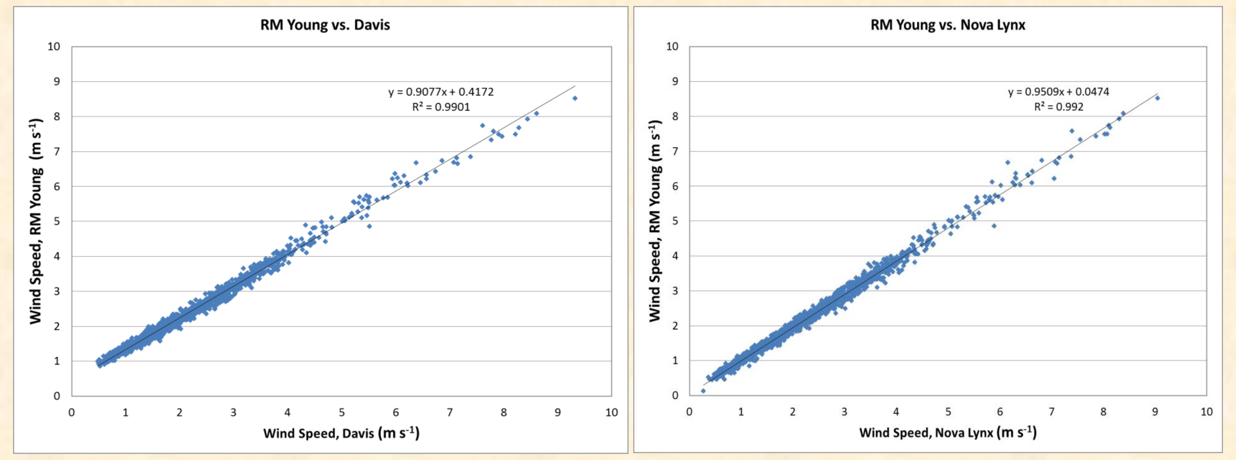
Wind

Measuring the RPM of the Inspeed Vortex sensor with an optical reader for comparison to the pulse measurement made by the Arduino.



Anemometer "shoot out" – comparing the test sensors to a Gill Metpak 2D ultrasonic and a RM Young Wind Monitor.

Three relatively low cost anemometers were tested: 1) Nova Lynx model 200-WS-02F, 2) Davis 6410, and 3) the Inspeed Vortex.



Field calibration of the Davis and Nova Lynx anemometers against the RM Young Wind Monitor.

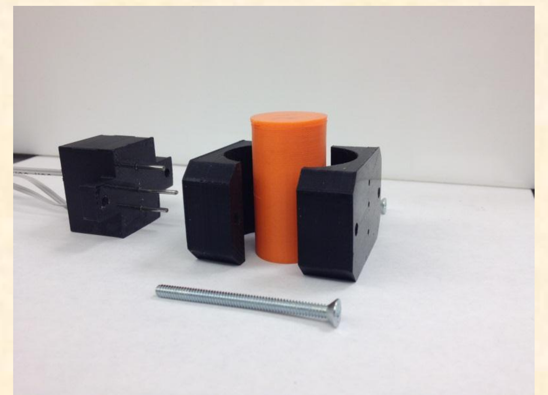
Anemometer Results

- The Arduino could measure and log the RPM of the anemometers accurately provided a debounce circuit was used.
- The Nova Lynx anemometers were within about 4 % or better of the RM Young and had a calibration coefficient of 1.21 mph per pps (pulses per second, Hz); the factory calibration was 1.25 mph per pps.
- The Davis instrument showed higher stall speeds, and significant bias and slope error when compared to the research grade instruments. The instrument would be fine for a hobbyist but is probably not adequate for most research.
- The wind vector (*as described used by the National Climatic Data Center*) was programmed into the Arduino code and included in the output.
- Next step: Test the Inspeed sensor and explore a 3D printable anemometer.
- Conclusion: The Nova lynx anemometer connected to an Arduino (with a proper debounce circuit) can provide very accurate wind speed measurements.

Precipitation

The Arduino logger described here is configured to read any tipping bucket rain gauge that generates a pulse (switch closure). Gauges from Nova Lynx and Davis were successfully tested.

Sap Flow

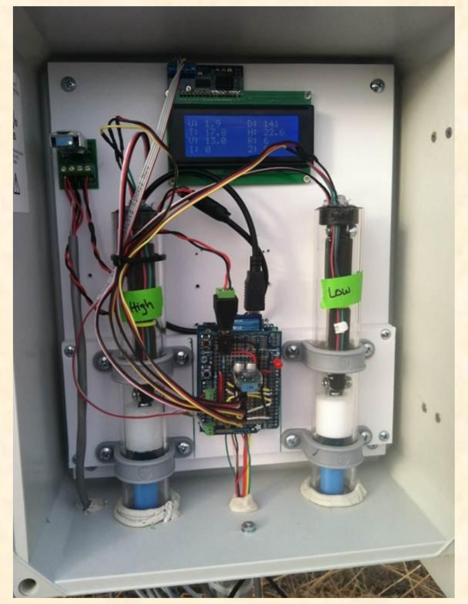


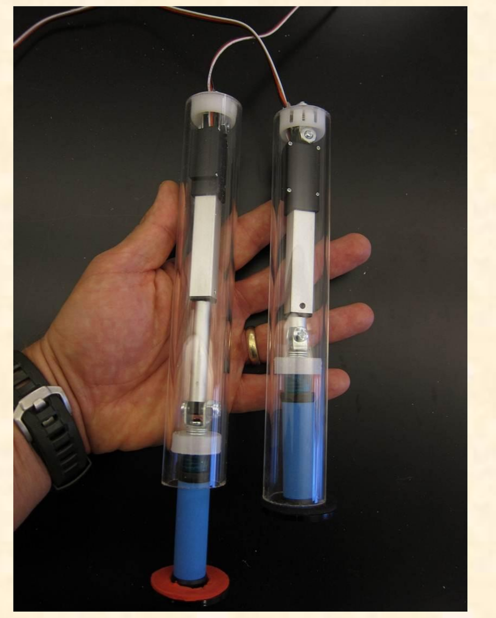
Heat-pulse sap flow gauges have been fabricated using the 3d printers and monitored/controlled with an Arduino-based logger.

Early prototypes of the sap flow gauge being tested in the greenhouse using gravimetric techniques. The total cost of building a two-gauge system (sensors and logger) is about $70.

Conditional Air Samplers for NH3

This Arduino base system is used to sample ammonia with passive samplers (Radiello) near cattle feedlots. The samplers remain sealed in a tube unless wind if from the direction of the source (150° arc) at sufficient velocity (>1.4 m/s). When deployed downwind they are typically exposed about 30% of the time. Often multiple samplers are deployed in a wireless network.





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