Low-cost, Low-profile Dendrometer Optimized for Grapevines

Cameron Clonch[1], Mark Huynh[1], Bryson Goto[1], Alexander Levin[2], John Selker[3], and Chet Udell[3]

[1]Openly Published Environmental Sensing (OPEnS) Lab, Oregon State University, Corvallis, Oregon, USA
[2]Department of Horticulture, Oregon State University, Corvallis, Oregon, USA
[3]Openly Published Environmental Sensing (OPEnS) Lab, Oregon State University, Corvallis, OR, USA

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Abstract

Increasing agricultural demand for fresh water resources in the face of a changing climate requires improved irrigation management solutions to maximize resource efficiency while maintaining crop yield and quality. Soil water deficits can significantly reduce plant growth and development, dictating the quantity and quality of the crop. While plant-based measures of water deficits are considered to be the best measures of water stress, current methods for achieving precise stress measurements are time-consuming and inefficient. Dendrometers are one plant-based tool that have shown potential to improve irrigation management in high-value woody perennial crops. High-precision dendrometers continuously measure small fluctuations ($\pm$ 1 micron) in stem diameter throughout the day, which directly correlates to water stress. However, currently available dendrometers are expensive, have mechanical hysteresis, and are subject to mechanical and environmental issues such as material expansion; weather and animal disruptions; and bulky, invasive design. The dendrometer created at the OPEnS Lab - tailored for grapevines - alleviates these key failure points through the use of zero-thermal expansion carbon fiber, spring tension, and a linear magnetic encoder. The design is also significantly less expensive than that of the competition, costing around $200 as opposed to $1000. Mass deployment of these automated dendrometers has the potential to provide a continuous picture of vineyard water stress at the whole-block level, thus providing valuable decision support for vineyard irrigation management. Follow the project at open-sensing.org/projects.

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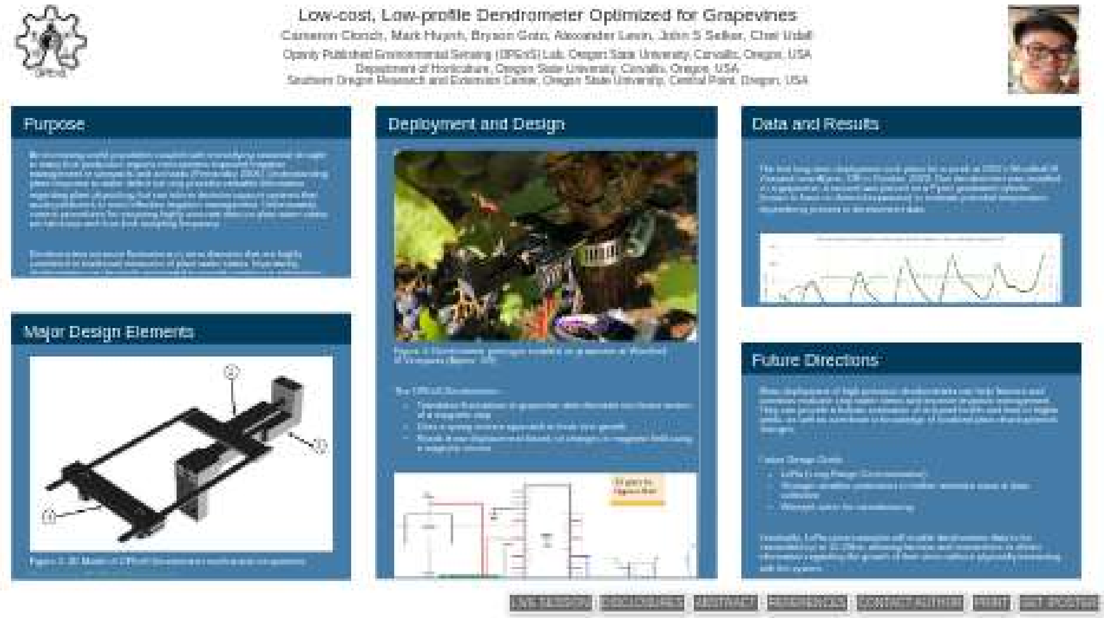

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Openly Published Environmental Sensing (OPEnS) Lab, Oregon State University, Corvallis, Oregon, USA
Department of Horticulture, Oregon State University, Corvallis, Oregon, USA
Southern Oregon Research and Extension Center, Oregon State University, Central Point, Oregon, USA



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PURPOSE

An increasing world population coupled with intensifying seasonal drought in many fruit production regions necessitates improved irrigation management in vineyards and orchards (Fernandez 2006). Understanding plant response to water deficit not only provides valuable information regarding plant physiology but can inform decision support systems that assist producers in more effective irrigation management. Unfortunately, current procedures for acquiring highly accurate data on plant water status are laborious and thus limit sampling frequency.

Dendrometers measure fluctuations in stem diameter that are highly correlated to traditional measures of plant water status. Importantly, dendrometers can be easily automated to provide continuous information over time. However, currently available dendrometers suffer from material expansion and interference from friction.

Utilizing an AS5311 magnetic sensor, we have developed a dendrometer with a spring-based design to mitigate these key failure points. Thus, our new dendrometer will help improve irrigation management methods by providing continuous, accurate, and precise measurements of plant water status. The refinement of this technology is crucial for conserving valuable freshwater resources and advancing agriculture towards a more sustainable future.

To learn more, check out our project Wiki:

OPEnSLab-OSU/OPEnS-Lab-Home

This is the homepage for the Oregon State OPEnS Lab. - OPEnSLab-OSU/OPEnS-Lab...

github.com

MAJOR DESIGN ELEMENTS

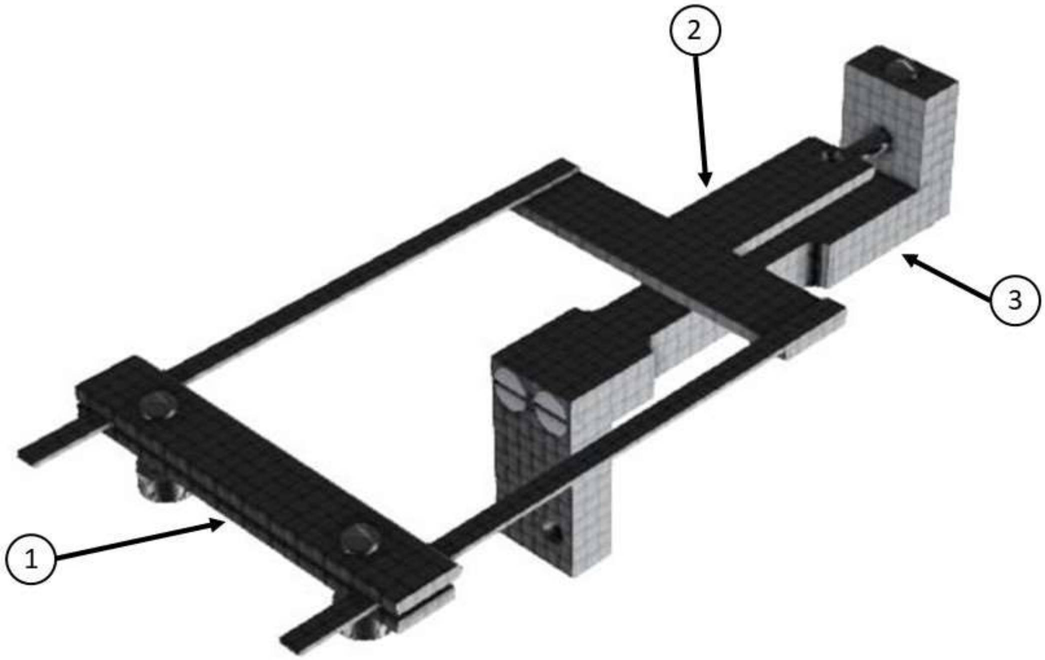


Figure 2: 3D Model of OPEnS Dendrometer mechanical components

Dendrometer 3D Model (Interactive) (https://a360.co/2IqXzXK)

- Fixture (1) at the end of the rods is removable
  - Placement is adjusted to fit stems 25mm – 40mm in diameter
  - Design can be modified to accommodate other stems sizes
- Spring enables T piece (2) to move linearly (magnet rests on the underside of this component)
- Motion is tracked by the AS5311 magnetic sensor, which is attached to the main long body (3)

AS5311 Magnetic Sensor

- Does not require contact between the sensor and magnet, enabling significant flexibility in mechanical structure
- Detects linear movement with a resolution of ~488nm
- Data saves to SD

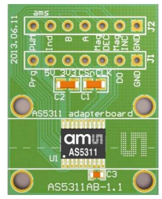
Spring Design

- Mitigates mechanical hysteresis by eliminating friction points that could impede motion that the sensor is supposed to read
- Reliant on tension only

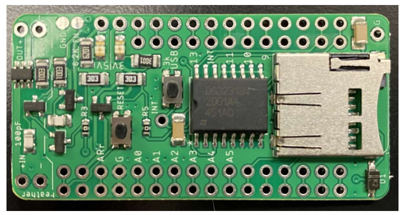
Carbon Fiber

- Lightweight
- Coefficient of thermal expansion approximately equal to zero
  - Material expansion/contraction does not confound with plant stem diameter measurements

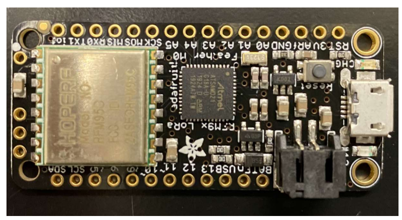
Component Breakdown



AS5311 Magnetic Sensor (https://ams.com/documents/20143/36005/AS5311_DS000200_2-00.pdf)



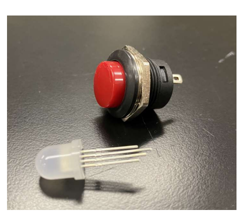
Hypnos Board (https://agu2020fallmeeting-agu.ipostersessions.com/default.aspx?s=19-A4-87-60-BC-82-F0-CA-E4-22-5D-32-0D-2C-89-DD&guestview=true) (Wiki) (https://github.com/OPEnSLab-OSU/OPEnS-Lab-Home/wiki/Hypnos)



Feather M0 LoRa

SHT-30 Mesh-protected Weather-Proof Temperature/Humidity Sensor

- Tracks ambient temperature and humidity for data validation purposes
- Range of -40 to +125°C



Button and NeoPixel Diffused 5mm Through-Hole LED

- Indicates whether or not the device has been properly installed

DEPLOYMENT AND DESIGN

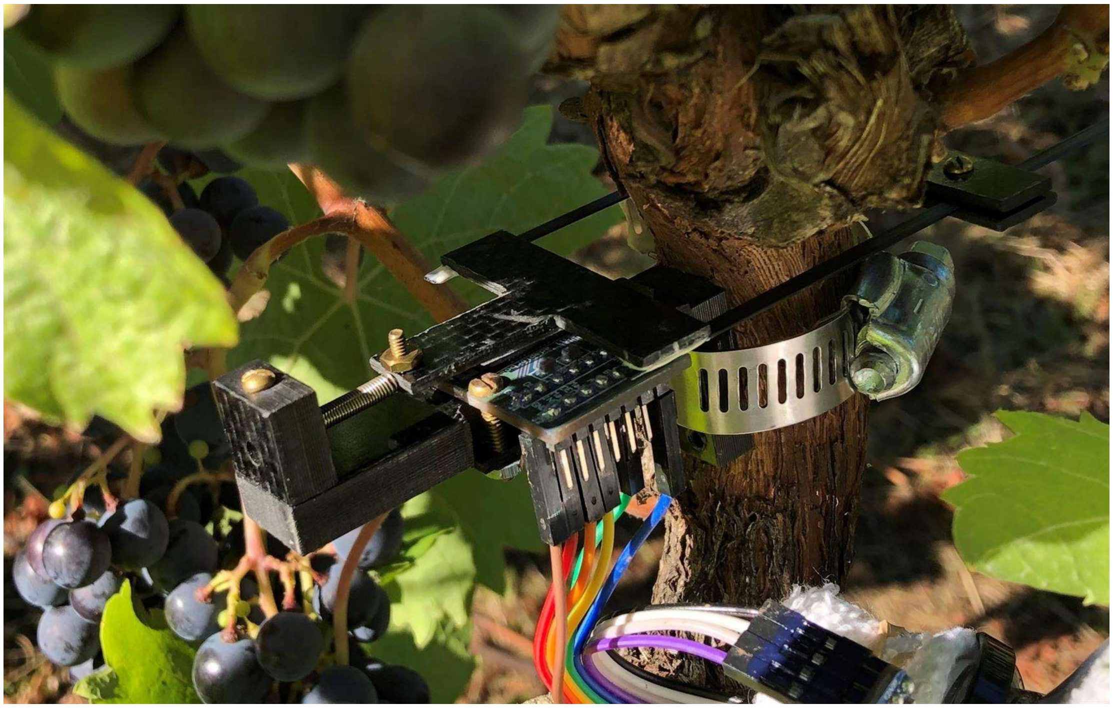


Figure 1: Dendrometer prototype installed on grapevine at Woodhall III Vineyards (Alpine, OR)

The OPEnS Dendrometer...

- Translates fluctuations in grapevine stem diameter into linear motion of a magnetic strip
- Uses a spring-tension approach to track vine growth
- Reads linear displacement based on changes in magnetic field using a magnetic sensor

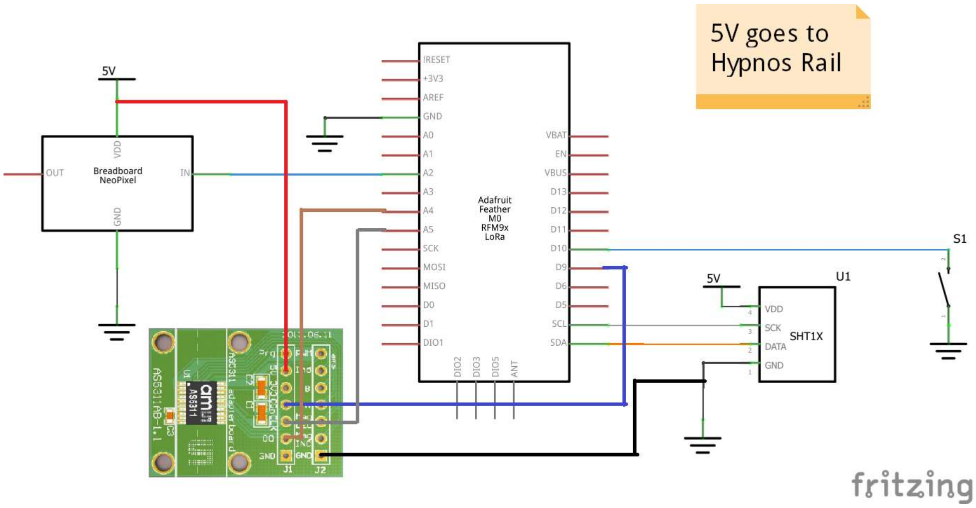


Figure 3: Dendrometer Wiring Diagram

DATA AND RESULTS

The first long-term deployment took place for a week at OSU's Woodhall III Vineyard near Alpine, OR in October, 2020. One dendrometer was installed on a grapevine; a second was placed on a Pyrex graduated cylinder (known to have no thermal expansion) to evaluate potential temperature dependency present in dendrometer data.

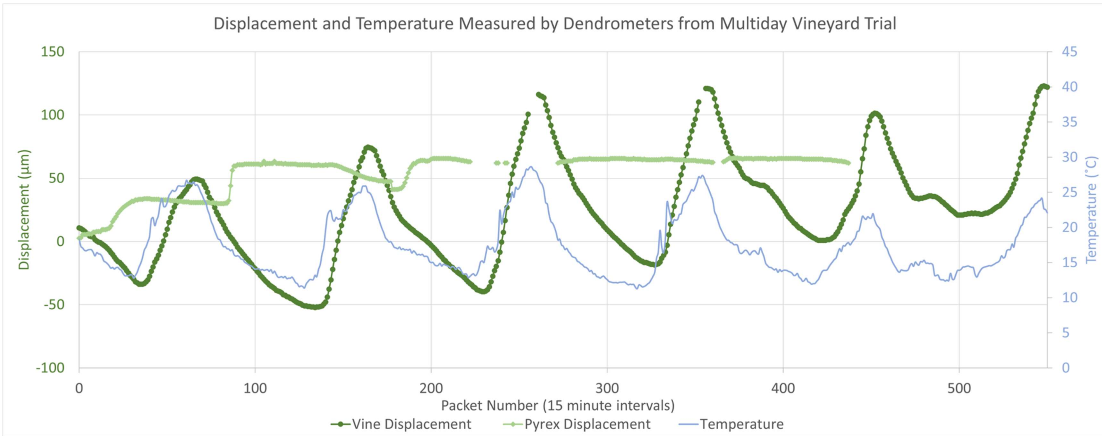


Figure 4: Displacement and temperature measured by the dendrometers. Displacement is recorded as a distance from initial position.

Results:

- Consistently tracking daily stem diameter changes of approximately 150-200µm
- Slight drift over time
- Device is mostly insensitive to temperature fluctuations
  - Maximum 30µm recorded movement per day on Pyrex cylinder

Current Draw Test:

- 0.2mA when sleeping
- 60 mA when awake and recording data
- Battery life of 916 days (2.5 years)

FUTURE DIRECTIONS

Mass deployment of high precision dendrometers can help farmers and scientists evaluate crop water stress and improve irrigation management. They can provide a holistic evaluation of vineyard health and lead to higher yields, as well as contribute to knowledge of localized plant developmental changes.

Future Design Goals:

- LoRa (Long Range Communication)
- Stronger weather protections to further minimize noise in data collection
- Waterjet cutter for manufacturing

Eventually, LoRa communication will enable dendrometer data to be transmitted up to 15-20km, allowing farmers and researchers to obtain information regarding the growth of their vines without physically interacting with the system.

DISCLOSURES

This work is supported by the USDA National Institute of Food and Agriculture, Hatch project NI18HFPXXXXXG055, and the National Science Foundation award #1832170.

ABSTRACT

Increasing agricultural demand for fresh water resources in the face of a changing climate requires improved irrigation management solutions to maximize resource efficiency while maintaining crop yield and quality. Soil water deficits can significantly reduce plant growth and development, dictating the quantity and quality of the crop. While plant-based measures of water deficits are considered to be the best measures of water stress, current methods for achieving precise stress measurements are time-consuming and inefficient. Dendrometers are one plant-based tool that have shown potential to improve irrigation management in high-value woody perennial crops. High-precision dendrometers continuously measure small fluctuations (± 1 micron) in stem diameter throughout the day, which directly correlates to water stress. However, currently available dendrometers are expensive, have mechanical hysteresis, and are subject to mechanical and environmental issues such as material expansion; weather and animal disruptions; and bulky, invasive design.

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REFERENCES

J.E. Fernandez and M.V. Cuevas, “Irrigation scheduling from stem diameter variations: A review,” *Agricultural and Forest Meteorology*, no.10, pp.136-149, Nov. 2009, doi: 10.1016/j.agrformet.2009.11.006.