High Precision Zero-friction Magnetic Dendrometer

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Abstract

Increasing agricultural demand for freshwater in the face of a changing climate requires improved irrigation management to maximize resource efficiency. Soil water deficits can significantly reduce plant growth and development, directly impacting crop quantity and quality. Dendrometers are a plant-based tool that have shown potential to improve irrigation management in high-value woody perennial crops (e.g. trees and vines). A dendrometer continuously measures small fluctuations in stem diameter; this has been directly correlated to water stress. While plant-based measures of water deficits are the best indication of water stress, current dendrometers are imprecise due to mechanical hysteresis and thermal expansion. The high-precision dendrometer created at the OPEnS Lab alleviates these key failure points using zero-thermal expansion carbon fiber, zero friction via a spring tensioning approach, and a linear magnetic encoder. The device achieves 0.5-micron resolution, and thermal fluctuations are less than 1 micron over diurnal swings of 25°C. The cost of the device varies with build quantity; parts are $200 - $450 each and assembly requires 6 to 12 hours per system. Dendrometers are currently being deployed with telemetry based on LoRa, which is under evaluation. Without solar charging and telemetry, the battery is sufficient for over two years of operation. Mass deployment of these automated dendrometers has the potential to provide a continuous record of water stress driven changes in stems, providing valuable decision support for irrigation management.

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ABSTRACT

Increasing agricultural demand for freshwater in the face of a changing climate requires improved irrigation management to maximize resource efficiency. Soil water deficits can significantly reduce plant growth and development, directly impacting crop quantity and quality. Dendrometers are a plant-based tool that have shown potential to improve irrigation management in high-value woody perennial crops (e.g. trees and vines). A dendrometer continuously measures small fluctuations in stem diameter; this has been directly correlated to water stress. While plant-based measures of water deficits are the best indication of water stress, current dendrometers are imprecise due to mechanical hysteresis and thermal expansion.

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PURPOSE

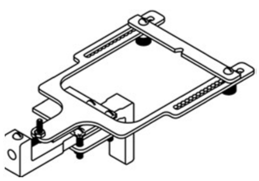

Figure 1: Mechanical body of the dendrometer as assembled.

Provide **continuous**, **accurate**, and **precise** measurements of plant water status using a **frictionless**, spring-based dendrometer design and magnetic encoder.

Better understand plant response to water deficit.

Improve **irrigation management** and **conserve valuable freshwater resources** in response to intensifying seasonal drought and increasing world population.

ACKNOWLEDGMENTS

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Clonch C., Huynh M., Goto B., Levin A., Selker J., Udell C., High Precision Zero-friction Magnetic Dendrometer. HardwareX, Vol. 10, 2021, e00248.

COMPONENT BREAKDOWN

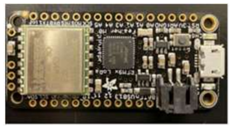

Figure 2: Feather M0 LoRa for data transmission and programming

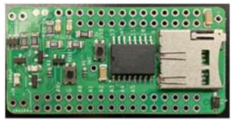

Figure 3: OPEnS Hypnos for power management

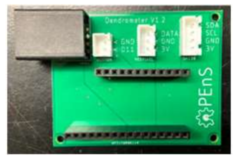

Figure 4: Custom PCB (with headers) for sensor connections

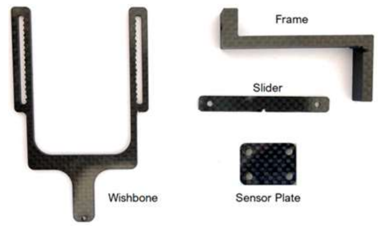

Figure 5: Waterjet-cut, carbon fiber mechanical components

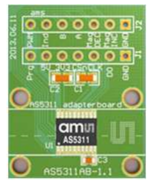

Figure 6: AS5311 Magnetic Sensor for tracking linear motion

Figure 7: SHT-30 Weatherproof Temperature/Humidity Sensor

Figure 8: Button and Neopixel LED to indicate system status

METHODS

Zero-friction
- spring-tension based
- magnetic encoder for tracking displacement

No material expansion
- carbon fiber fabrication for near-zero thermal expansion

High precision
- tracks linear motion at 0.5μm precision

Telemetry capabilities
- live-tracking of data
- possibility of creating active sensor network

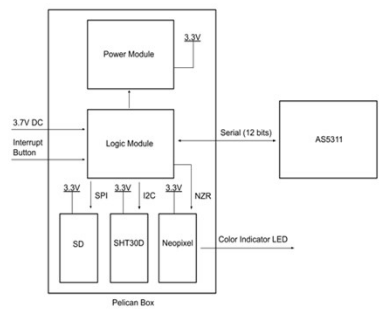

Figure 9: Block diagram of Dendrometer electronics

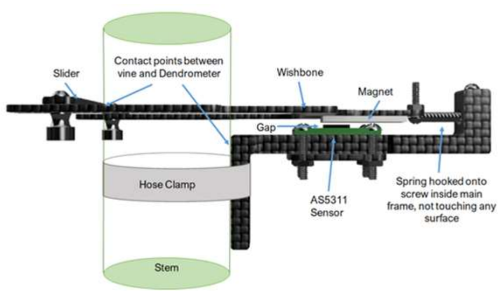

Figure 10: Mechanical dendrometer components on a stem. If the stem diameter expands, the slider is pushed outward and the spring is stretched. Since the slider is secured onto the wishbone, which is connected to the spring, the magnet that is on the wishbone experiences the same horizontal movement as the slider. The magnetic sensor can track the linear movement of the magnet through the change in magnetic field strength using the Hall effect.

TESTING

Figure 11: Dendrometer installed on a grapevine (Vitis vinifera L.) at Southern Oregon Research and Extension Center (SOREC) in Central Point, OR. Seventeen devices were ***deployed for 6-12 weeks during summer 2021***. The devices were deployed on plots receiving ***two different water treatments***.

Figure 12: Dendrometer installed on a blueberry plant (Vaccinium sect. Cyanococcus) at Lewis- Brown (LB) Farm in Corvallis, OR. We have validated all our devices and conducted various tests at LB Farm since May 2021.

RESULTS

Validation Tests
- **Stem diameter fluctuations correlate with Vapor Pressure Deficit (VPD), not temperature**
  - Despite a temperature change of 6°C on 2/5, displacement measurements show negligible change

SOREC Deployment
- *Dendrometer 5* shows trunk diameter **fluctuations of 120 μm/day** on average
- *Dendrometer 13* **fluctuates 50 μm/day** on average

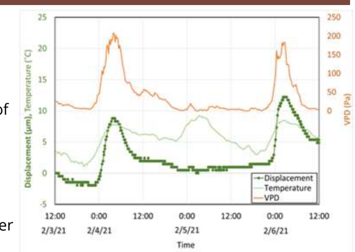

Figure 13: Sample of dendrometer data from tests to confirm VPD and displacement trends match, and that there is negligible temperature dependence.

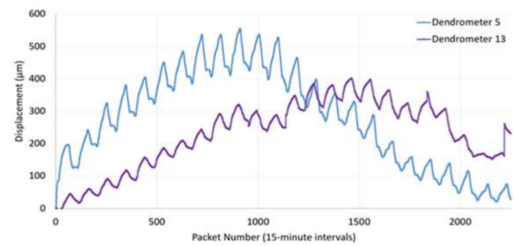

Figure 14: Displacement data from two dendrometers at SOREC for one month of the summer deployment. Dendrometers 5 (blue) and 13 (green) received different irrigation treatments for the duration of the growing season.

CONCLUSIONS: FUTURE DIRECTION

The OPEnS dendrometer can assist in water conservation efforts and be used to achieve customized fruit characteristics.

We plan to deploy 32 dendrometers on grapevines at the Southern Oregon Research and Extension Center for the 2022 growing season (May-October). LoRa telemetry will be utilized, enabling rapid evaluation of stem diameter fluctuations.

During the winter/spring of 2022, we will conduct more tests at LB Farm, on plants in a greenhouse on the OSU campus, and in-lab to explore the range of possibilities for the device. We also plan to further analyze the data from the SOREC 2021 deployment by comparing the displacement measurements with data collected from other sensing devices in the field (i.e. soil moisture sensors) at the time.