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 sensing tools 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 is 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, internal friction, 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. 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**. With telemetry, the battery can last upwards of three months. 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.

The dendrometer has recently gone through an update to its carbon fiber assembly, known as V2. A new protective case was also created to improve the robustness of the design.

PURPOSE

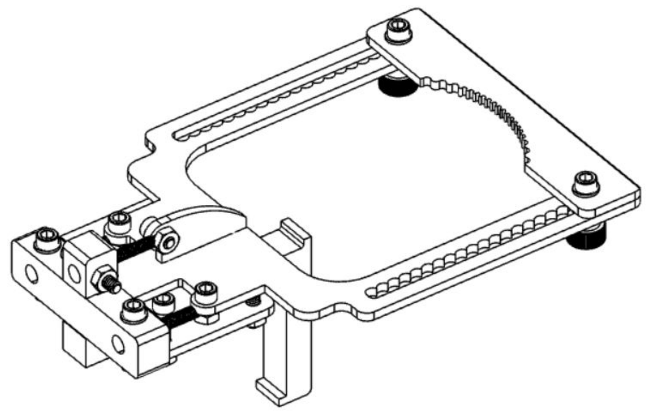

Figure 1: Mechanical body of the V2 dendrometer as assembled.

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.S., Udell C., High Precision Zero-friction Magnetic Dendrometer. HardwareX, Vol. 10, 2021, e00248.

COMPONENT BREAKDOWN

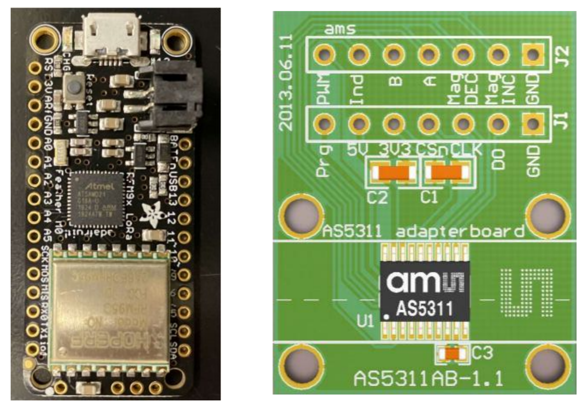

Figure 2: Feather M0 LoRa for data collection and transmission, and AS5311 Magnetic Sensor for tracking linear motion

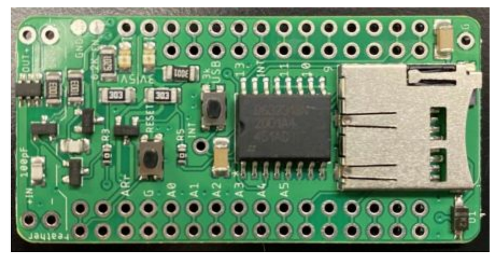

Figure 3: OPEnS Hypnos for power management

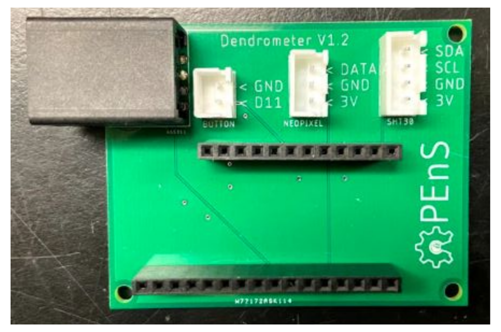

Figure 4: Custom PCB (with headers) for sensor connections

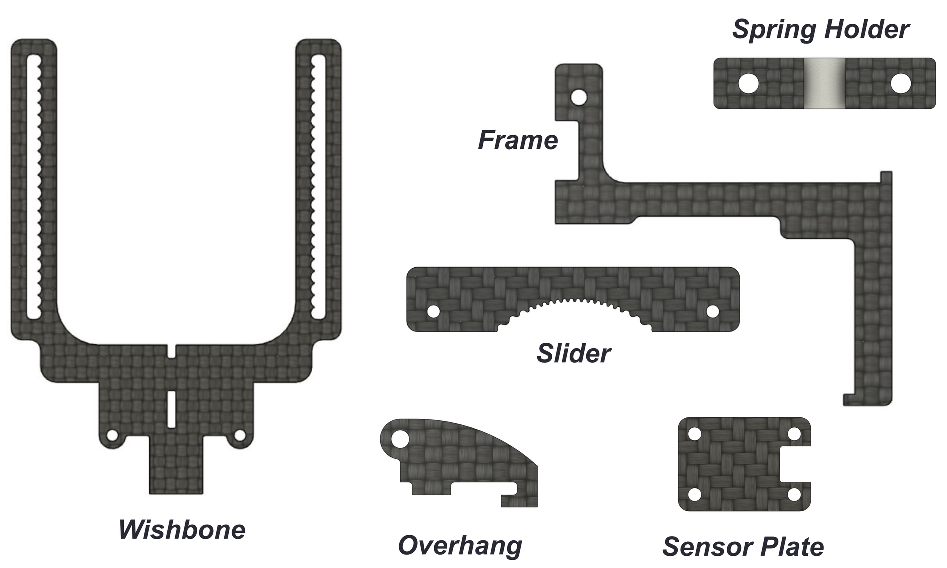

Figure 5: Waterjet-cut, carbon fiber mechanical components

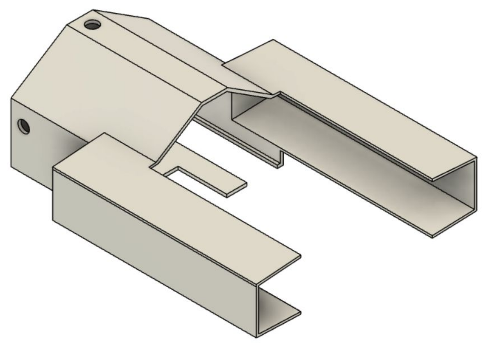

Figure 6: 3D printed "Barn" that protects the sensors

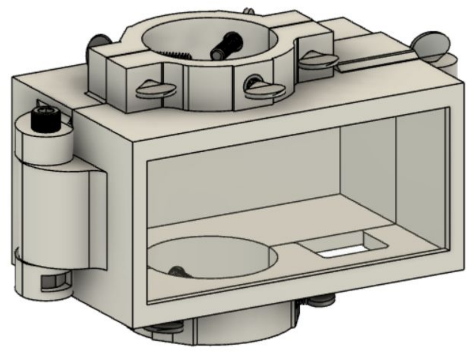

Figure 7: 3D printed protective enclosure

METHODS

Zero-friction
- spring-tension based
- no-contact magnetic sensor

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
- data from many-device network displayed at one hub

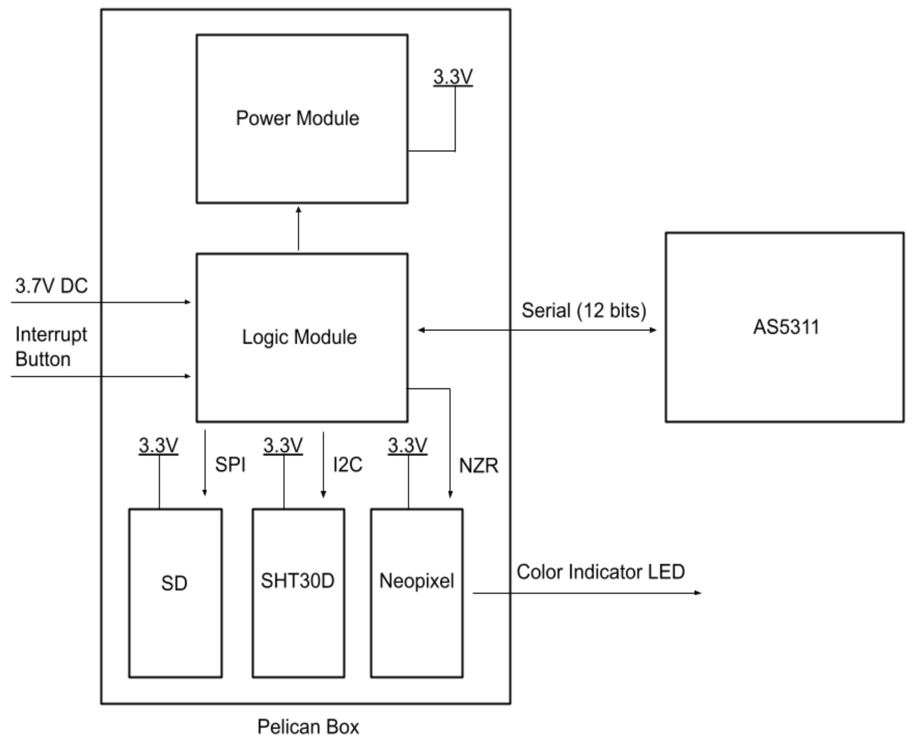

Figure 8: Block diagram of Dendrometer electronics

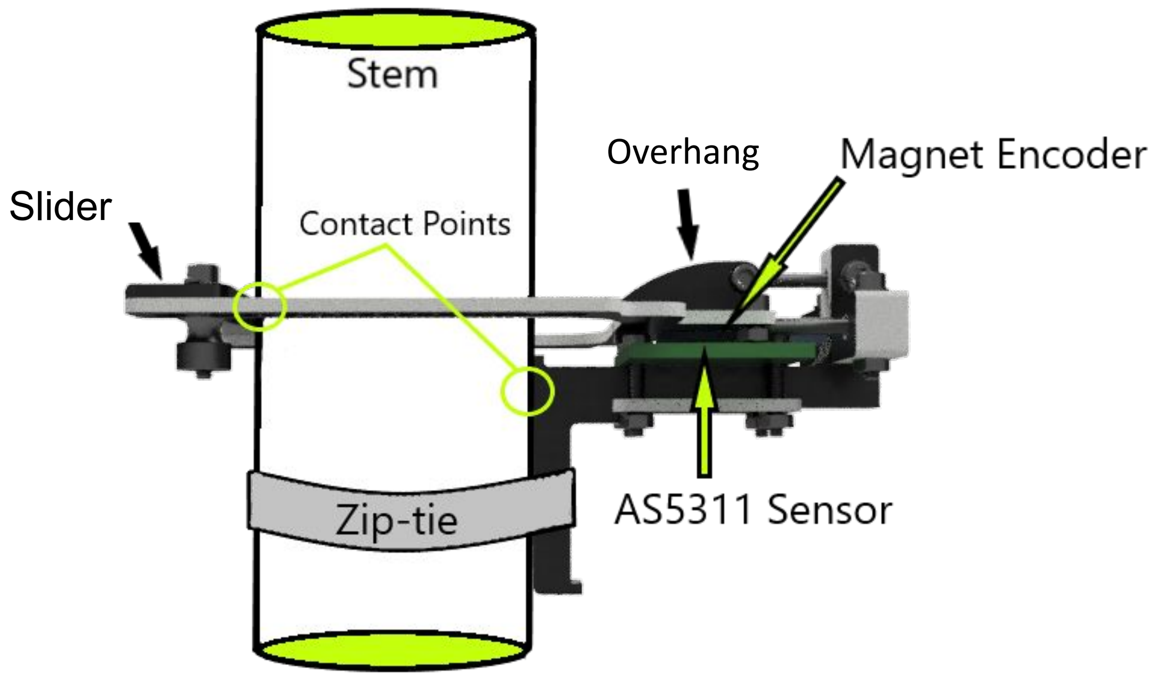

Figure 9: **Mechanical dendrometer components.** If the stem diameter expands, the slider is pushed outward and the springs are stretched. The slider can be adjusted and secured to accommodate a variety of stem sizes and shapes. The entire slider assembly moves as a rigid body, including the sensor magnet. The magnetic sensor can track the linear movement of the magnet using the Hall effect. There is no friction in the system.

CHANGES BETWEEN V1 and V2

Overall Size
- The size of the wishbone and frame were reduced to save costs in material and manufacturing time. There are more individual components with the addition of the spring holder and overhang pieces but there was an **overall cost savings of 37%.**

Protective Covers
- Figures 6 & 7 show the two different protective covers were designed. These enclosures will protect the device from outside disturbance, **reducing error in data collection.**

3 Springs
- Three springs were incorporated, as opposed to the singular spring in V1, to limit axial rotation and make the dendrometer more reliable. **Misalignment was significantly reduced** from this design modification, performing better on both vibration and knock testing.

Sharkbite Slider
- The V1 slider had a small notch in the middle to assist with alignment but did not reduce slipping of the wishbone on the plant. By using a "shark bite" pattern instead of a notch, the grip strength on the plant increases and keeps the device where it needs to be. This change resulted in **a 32% increase in static friction.**

Narrowing Magnet
- The space between the sensor, magnet, and wishbone has very low clearance. The screws that attached the sensor to the mounting pieces interfered with the sensor and previously required a long grinding process to all fit. By clipping the magnet and making it narrower, these problems are avoided in V2, decreasing cost and manufacturing time as well as increasing ease of installation.

TESTING

Figure 10: 3D printed dendrometer installed on a blueberry plant at Lewis- Brown (LB) Farm in Corvallis, OR. The initial rounds of prototype testing were conducted with 3D printed parts of the new dendrometer and changes validated.

Figure 11: Carbon fiber V2 dendrometer installed on a plant outside the OPEnS Lab. This was used to test the reliability of the new V2 design with data collection as well as the robustness of the 3D printed protective enclosure

Figure 12: Closeup of V2 design attached to a plant stem. In the future, we plan to replace the hose clamp that secures the frame to the stem with a zip tie to allow for faster installation and removal.

SUMMARY AND RESULTS

Initial testing of the revised design showed that the measured displacement remains correlated with VPD, confirming that changes made in V2 did not reduce functionality.

The OPEnS dendrometer has the potential to improve agricultural water conservation by providing **continuous, remote, and low-cost** measurements of plant water stress. Once calibrated to physiological data, the output from the device will inform managers and irrigators on when to apply water based on their production goals, thus **optimizing on-farm inputs.**