A PCB Based Sap Flux Sensor for Increased Manufacturability and Lower Cost

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Abstract

Sap flux probes have been used to study sap velocity since the early 20th century and have progressively improved in accuracy and usability. Advances are also being made in making these devices cheaper via open-sourced projects; however, these solutions require extensive time and skill to construct a reliable device. When our lab tried to replicate Miner's results, only two of the first ten probes built passed rudimentary testing. We therefore redesigned the system in a PCB-based design that simplifies construction, and presents opportunity for automated mass manufacturability at a scale not possible with existing designs. New designs for both the Thermal Dissipation Method (TDM) and the Heat Ratio Method (HRM) techniques were tested. We present our open-source designs for wireless sap flux probes that communicate over 2km using the LoRa protocol through canopy to an internet hub, where data is logged in near-real-time and accessible online.

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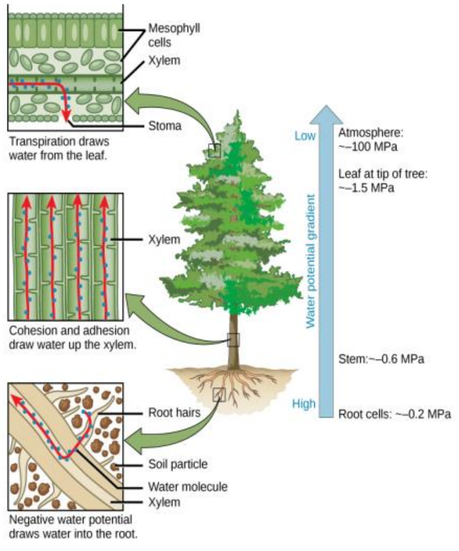
H13P-1984

Abstract

The amount of sap flowing through a plant (transpiration) is analogous to the numbers of calories an animal consumes. The quantity of water transpired has a direct relationship with plant productivity (GPP) and photosynthetic activity.

Today, sap flow measurements are used in a plethora of fields including horticulture, hydrology, water conservation, civil engineering, urban tree management, and mining [2].

Two methods of measuring sap are examined: thermal dissipation method (TDM), and heat ratio method (HRM).

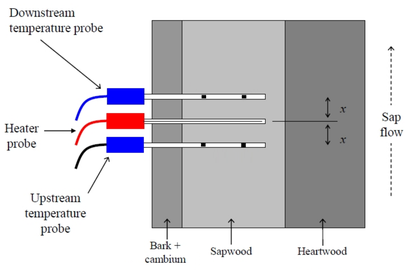


Early design of the sapflowmeter installed in a banana plant.

Objective + Theory

A heat ratio method (HRM) sapflow sensor has three probes: two temperature sensors and one heater probe.

The sensor measures the flow of sap by examining the temperature differential between the downstream and upstream probes.



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The PCB sapflowmeter project is an attempt to drastically reduce the cost to manufacture sap flow sensors by using a new open-source PCB based design that can be assembled with a pick and place machine.

The end design needed to be:

- Small enough to avoid damaging the plant
- Comparably accurate when compared to commercial probes
- Significantly less expensive than current designs

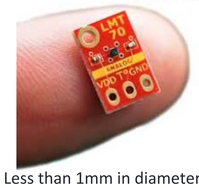
Design & Construction

Probe Design

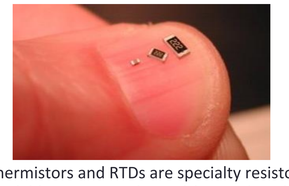
Delivering Heat
A heat pulse is generated by running a set current through a high wattage resistor

Sensing Temperature
This design is compatible with many different temperature sensors.

- Solid state IC
- Thermocouple
- Thermistor
- RTD



Less than 1mm in diameter, the LMT70 is the world's smallest IC temperature sensor.



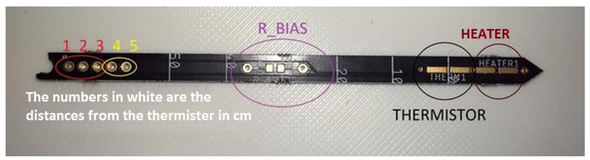
Thermistors and RTDs are specialty resistors; available in SMD packages (shown above)

Thermocouple junction, the most common temperature sensor.

Probe Construction

A. PCB is etched and populated by a pick-and-place machine
B. The PCB is potted in thermally conductive epoxy such that it will fit into a drilled tree hole
C. (Optional) The outside of the epoxy is coated in a waterproofing layer using conformal coating
D. Secure probes in a 3D printed housing

Step A

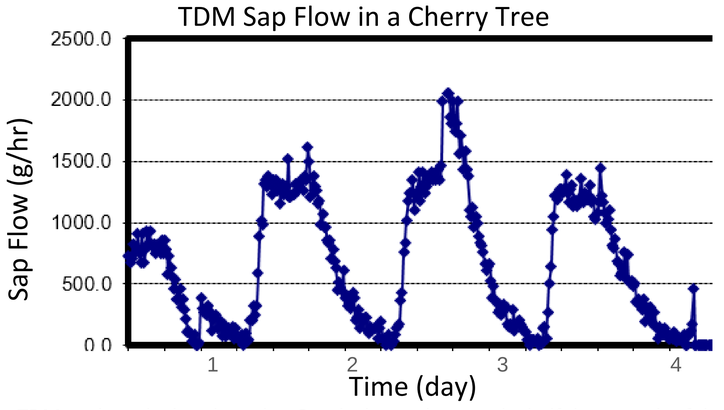


Step B,C

Step D

All probes are identical, having slots for both a heaters and temperature sensors. A 3D printed housing secures the probes in place. By using a 3D printed housing and multipurpose probes infinite sensor geometries can be built using the same parts; including HRM (Step D, right), TDM (Step D, left) sap flow sensors.

In-vivo Results



TDM probe calculated results. Graph shows three and a half days worth of data taken from a Cherry Tree taken during mid August.

For longer tests, the temperature probes began to malfunction caused by water shorting the thermistors and sensors drifting over time. Probe waterproofing and handling sensor drift over time are two unsolved problems with this design.

Future Development

Sensor Comparisons
- Performing various experiments to determine which temperature sensor will perform best

In-Vitro Testing
- Shown right. Pumping known amount of water through a tree stem

Long-Term Tests
- Full season experiments to determine evapotranspiration in fruit trees

Project Loom
- Integrate the sensor into the OPEnS Lab's Project Loom ecosystem

Example of in-vitro sap flow calibration experiment on a kiwi plant [1].

ACKNOWLEDGMENTS

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Citations:

1. Prendergast, P.t., et al. "Water Use By A Kiwifruit Vine: Calibration, Measurements And A Model." *Acta Horticulturae*, no. 753, 2007, pp. 535–538., doi:10.17660/actahortic.2007.753.70.
2. Monitoring tree water use in the field: training template, Julius Njoroge & Prof. Catherine Muthuri