An autonomous IoT operated linear magnetic driven dendrometer from detecting stem radial increment

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Introduction

This study aimed to design, build, and deploy an IoT-driven radial dendrometer using a linear magnetic encoder, with calibration methods that are both simple and robust, including temperature sensitivity. Radial growth is a critical parameter in forest surveys, playing a vital role in understanding stem water dynamics and supporting research that links ecosystem processes with individual tree functions. Despite the significance of radial growth measurement, advancements in dendrometer technology have been limited. This research focuses on developing a dendrometer capable of quasi real-time monitoring of stem radial increments, driven by a commercial linear magnetic encoder and integrated with the TreeTalker® IoT platform. The study also evaluates the dendrometer's functionality, from calibration to field deployment, and its accuracy in detecting fine-scale changes in radial stem increment.

Materials and methods

- The dendrometer system developed in this study uses a high-resolution, contactless linear magnetic encoder (AS5311) from AMS OSRAM GmbH, This sensor detects position changes along a magnetic tape without physical contact, reducing wear and tear issues common in other systems like LVDTs and linear potentiometers. The sensor's 0.488 µm resolution makes it suitable for long-term monitoring of daily stem shrinkage and swelling patterns.
- A linear magnetic tape with alternating 2 mm dipoles, provided by BOGAN GmbH, serves as the magnetic object. The tape has a ±40 µm/m accuracy class. Position detection is facilitated by the AS5311's Pulse Width Modulation (PWM) output, with a 1 µs pulse width corresponding to 0.488 µm of movement.
- To handle the sensor's digital output and account for incremental shifts in linear position, a custom Python package was developed. The dendrometer distance values are influenced by the orientation of the magnetic tape, which affects the digital signal depending on whether the tape moves from North to South or vice versa (Fig. 1)

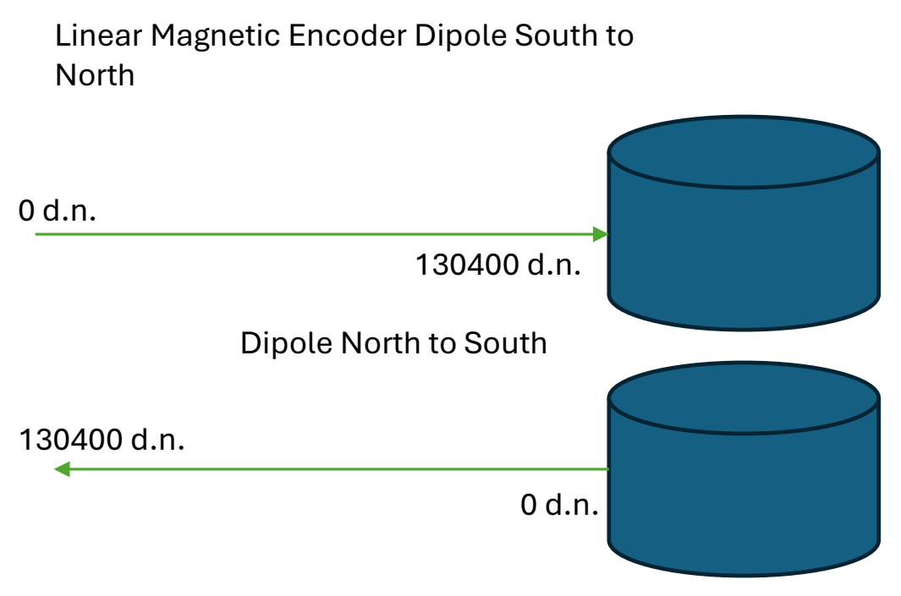


Figure 1: Characterization of the orientation of the linear Magnetic Encoder and resulting digital number response S-N 0 to 130400 as opposed to N-S 130400 to 0

Dendrometer Sensor Design and Features

The radial dendrometer developed in this study employs a piston-based system similar to LVDTs and potentiometers, using a linear arm that contacts the tree stem to measure radial increments. Each unit, numbered 1 to 5, features the following components (Fig. 1):

1. Linear Arm: A 65mm grooved arm with a holder for a 35mm magnetic tape and a 20mm mounting plate for attachment to the tree stem.
2. Rail Block: An MGN9C rail block mounted to a brace, functioning as the slider for the linear arm.
3. Sensor Holder: A dedicated holder for the AS5311 chip.
4. Mounting Rods: Two 3mm carbon fiber rods for embedding the system into the tree.
5. Protective Cover: A cover to shield the system from rain and dust.

Data acquisition is handled via PWM, 5V, and Ground pins on the AS5311 board, interfacing with TreeTalker+ 3.1 and 3.2 versions.

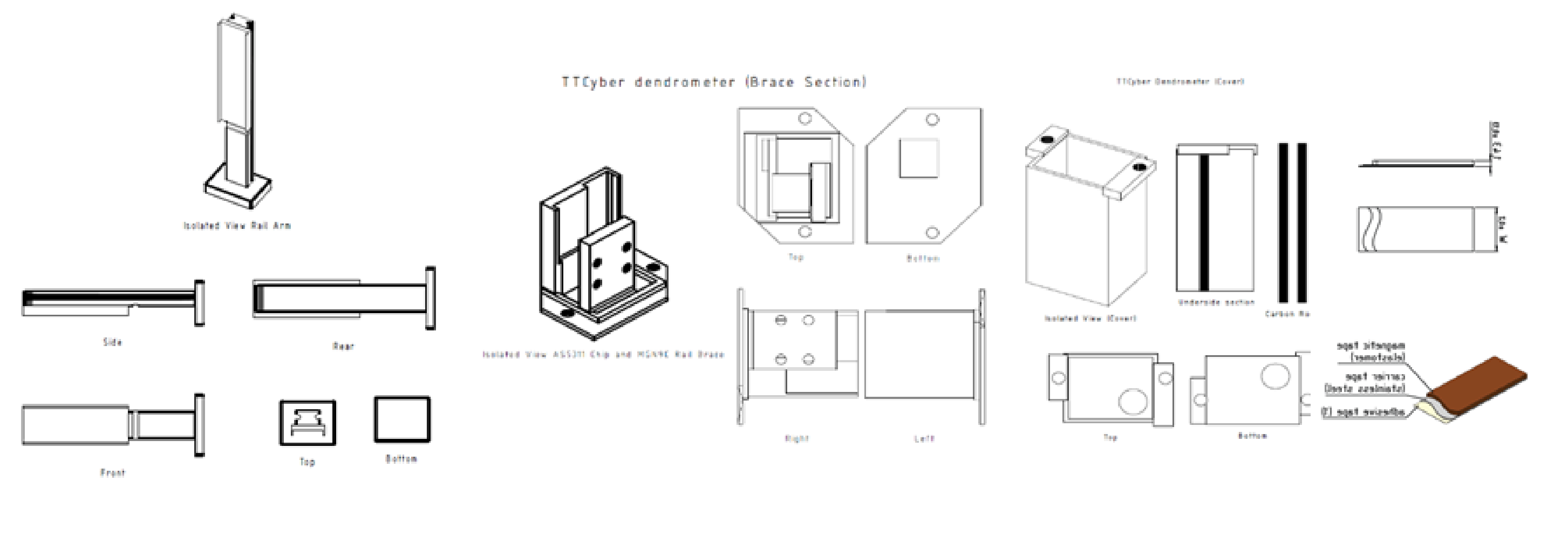


Figure 2: Design schematic from CAD with components of the Autonomous dendrometer

Results

The results from the calibration (Fig. 3) suggest a highly accurate and stable sensor design with RMSE = 50 micron over 2mm and an R2 of 0.99. The sigmoidal effect of the calibration is caused by an ACD filter on the TT+ hardware causing some tailed error increase.

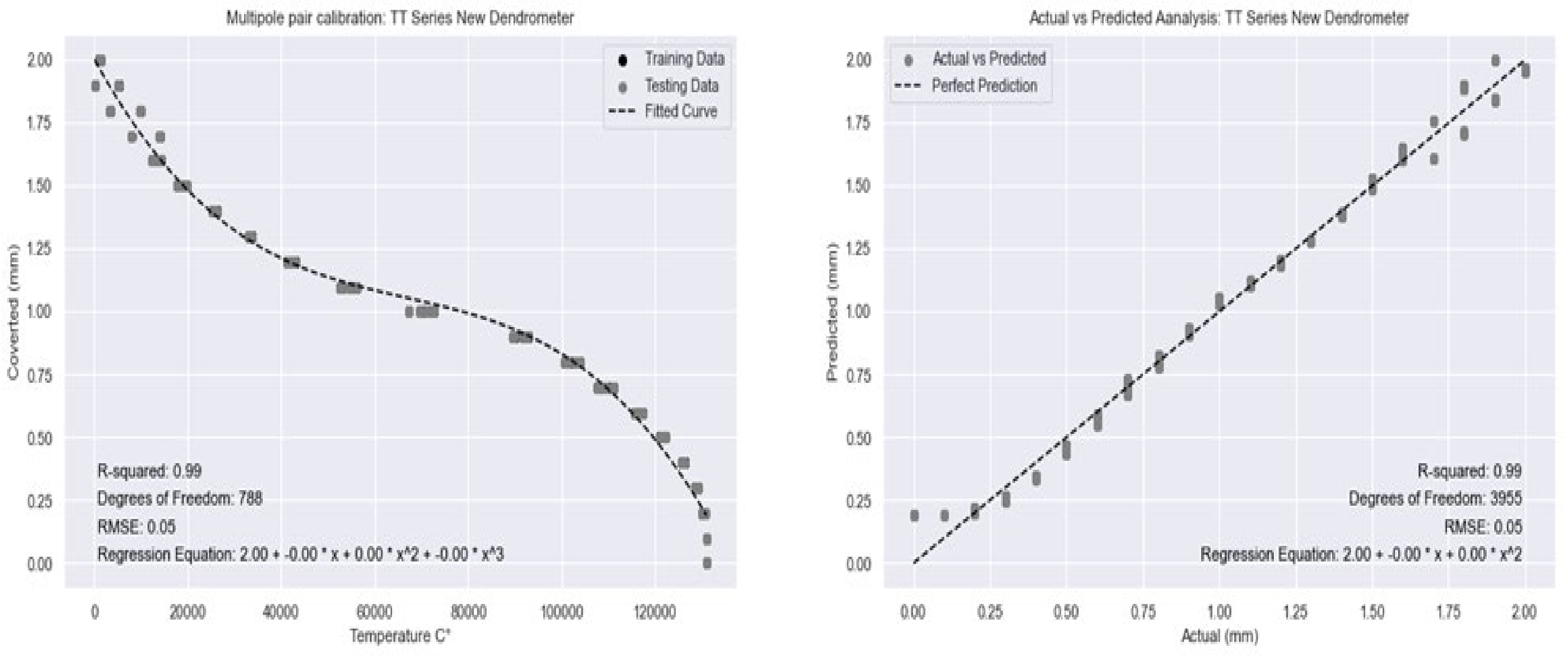
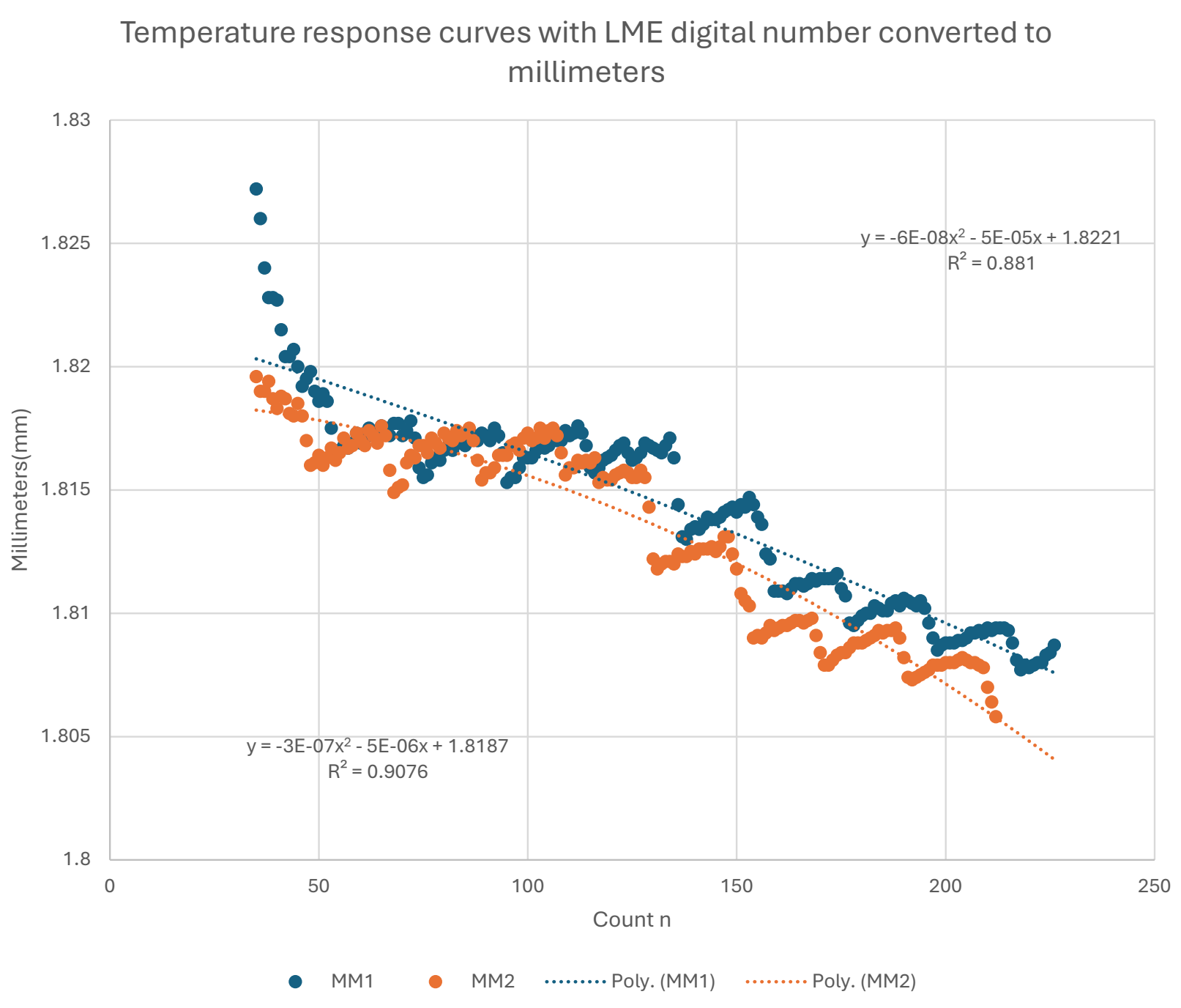


Figure 3. Calibration curves and function from experiments using a stepper motor with a 0.1mm incremental step. Regression analysis of performance using actual versus predicted analysis.

Temperature sensitivity

The sensor and material (PLA+) for the casing preformed reasonably well with a negligible impact from temperature exposure. In both trials temperature impact equated to approximately 0.3microns > for every 1° C change over 40° C. This was maintained for both positive and negative calibration functions and is negligible.



Rate of change from 0-40+ degrees Celsius (Calibration inverse)	
	Slope Value (mm)
Trial 1	-0.000303
Trial 2	-0.000280
Rate of change from 0-40+ degrees Celsius (Calibration Parallel)	
Trial 1	0.000292
Trial 2	0.000271

1C° = -0.00029 mm (High-Low)
1C° = 0.000282 mm (Low-High)

Figure 4: Temperature sensitivity results using a climatic chamber with a 5-degree increment at 30 minute intervals from 0-40°C

Field results monitoring

The dendrometer performed remarkably well when compared with the D1 UMS static diameter belts and demonstrated reasonable stability. The peaks identified in (Fig. 5) are associated with the algorithm used to processes the changes in di poles of 2mm. This feature was negated by applying a simple moving average (SMA) and an exponential average (EMA) in particular. The stem grew by approximately 1.49mm for the period of observation for 2023.

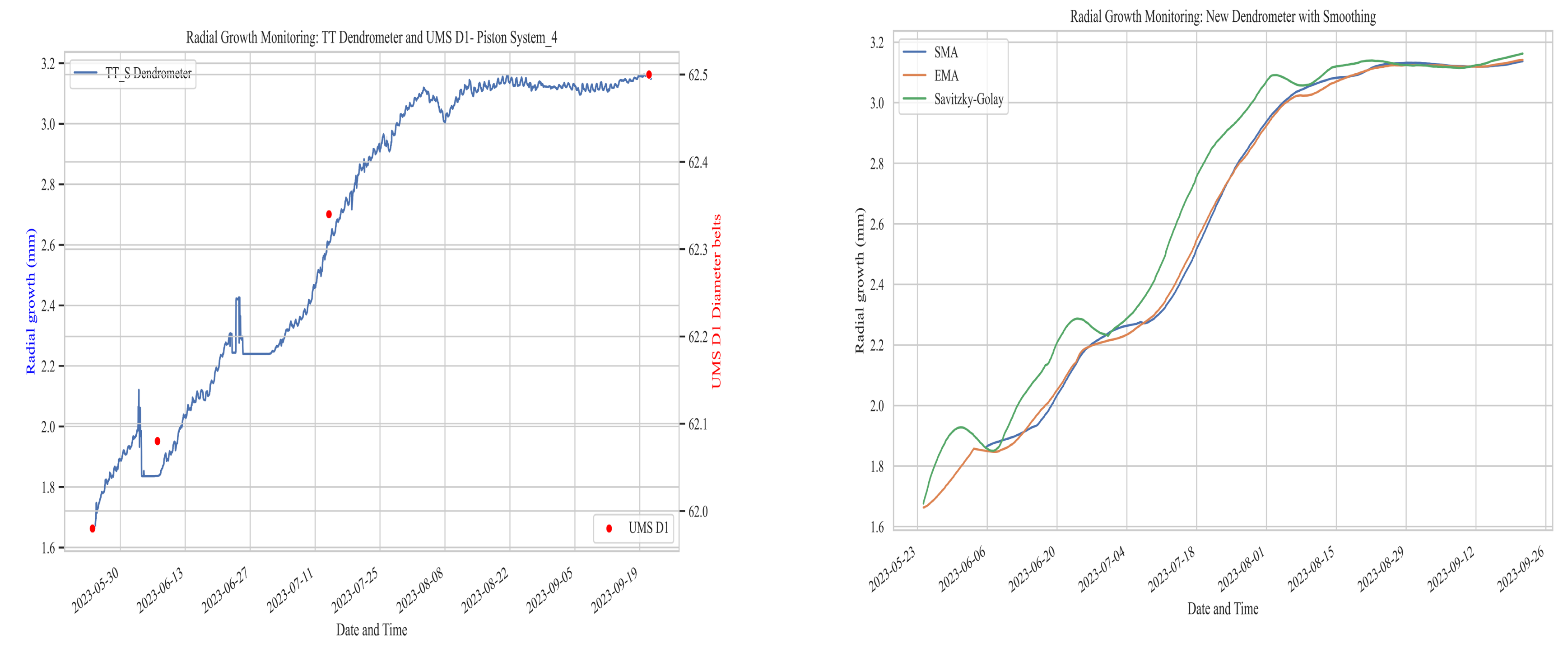


Figure 5: Seasonal monitoring of *P. Abias* Lavarone Trento 2023 using the dendrometer comparing UMS D1 static diameter belts as reference. Smoothing of data results using Sav_gol, SMA and EMA approaches.

Detecting diel stem dynamics

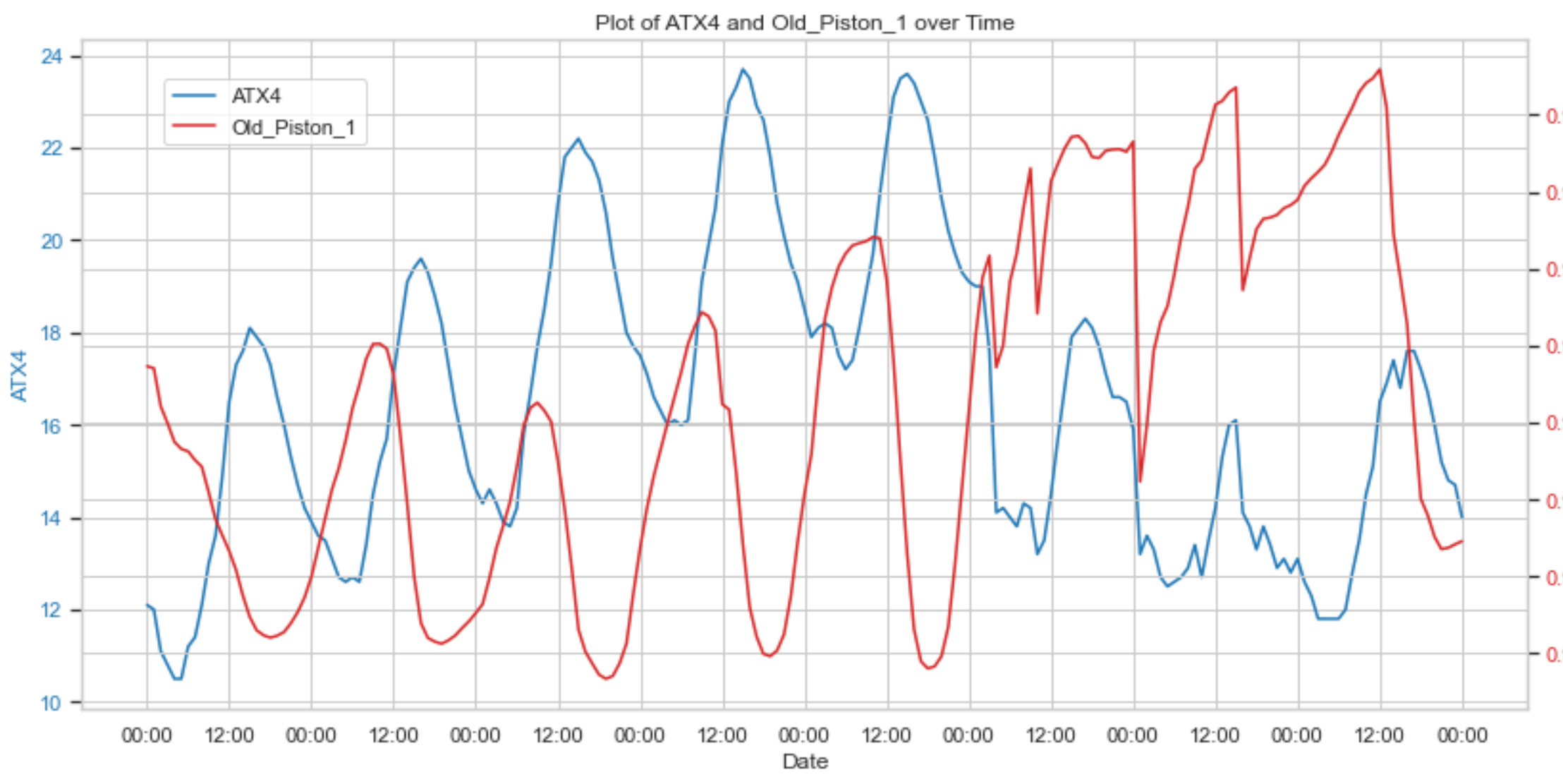


Figure 6: Diel shrinking swelling stem oscillation detection using new dendrometer with maximum shrinking occurring at midday and swelling at midnight.

Stem diel patterns of shrinking and swelling were observed (Fig. 6). A displacement in synchronicity between max daily temperature and stem shrinking and *visa versa* for swelling and night temp.

Conclusion

The ‘bottom up’ design and deployment of a new dendrometer for detecting changes in stem radial increment were investigated. The results suggest that while sensor performance under lab conditions were excellent, the impact of the ACD Filter could impact the overall precision of the system when applying the calibration function to the actual conversion of sensor readings to millimeters, impacting physical measurement accuracy. Seasonal monitoring are relatively well represented according to the comparison between the D1 diameter belts with an average deviation of approximately 1%.

Finer scales shrinking and swelling appear to be captured, however further trials and comparison with other devices should be undertaken. While temperature impacts appear negligible, further study into system design should be pursued both to increase durability as well as isolate the system further.

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