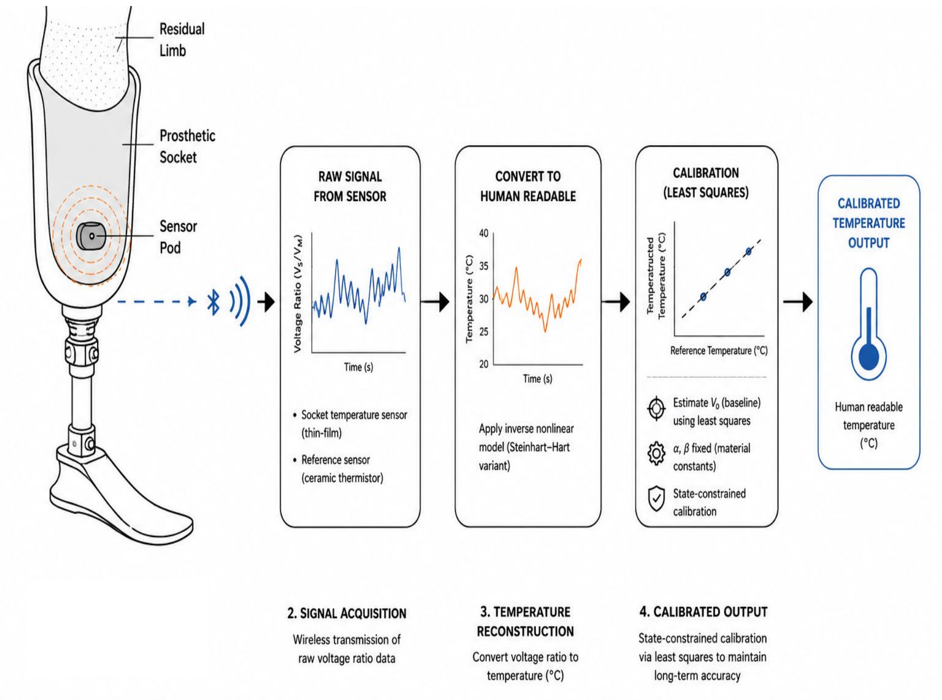
Dynamic Calibration of Nonlinear Temperature Sensors for Residual Limb Monitoring

Chrispin Kabuya

SAIP 2026 Oral Presentation

Track: F - Applied Physics



Co-Authors:

B. Magunje (iYunivesithi Walter Sisulu)

D.T. Britton (PST Sensors Pty Ltd)

M. Harting (PST Sensors Pty Ltd)

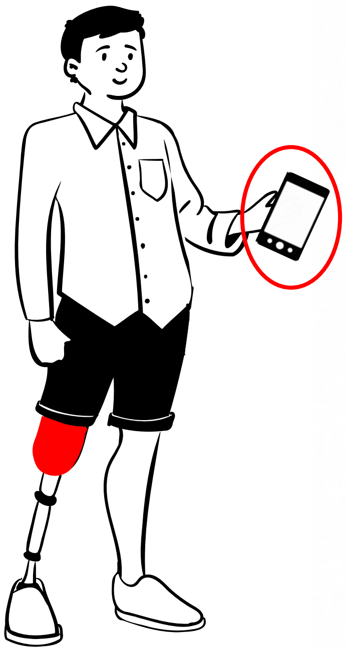
iYunivesithi Walter Sisulu

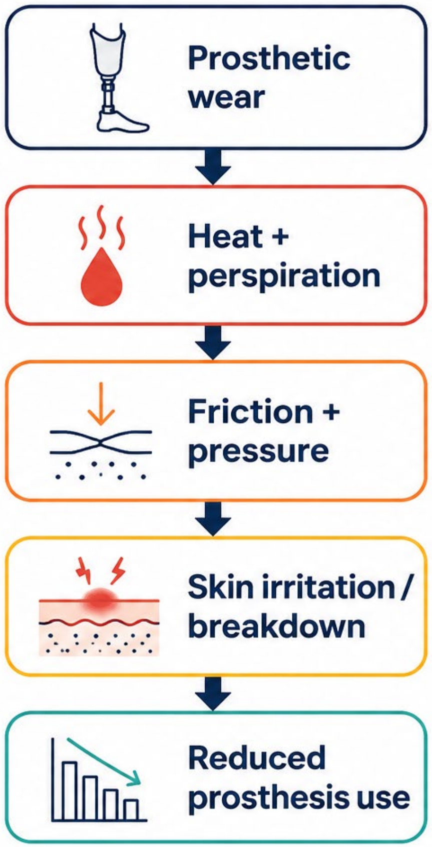
nano-micro manufacturing facility

PST SENSORS

70th ANNUAL CONFERENCE OF THE SOUTH AFRICAN INSTITUTE OF PHYSICS

Why Residual Limb Monitoring Matters





- Residual-limb skin is exposed to shear, pressure, warmth and moisture.
- Heat and perspiration inside the socket affect comfort, suspension and tissue health.
- Self-reports are inaccurate and Clinic reviews are infrequent
- Continuous monitoring can support early warning before serious tissue damage develops.

Research Question & Objectives

Can long-term sensor drift be compensated automatically while maintaining accurate residual limb temperature measurements?

- **Objective 1**: Develop dynamic calibration.
- **Objective 2**: Enable reliable long-term monitoring.
- **Approach**: Multi-scale temporal framework (morning equilibrium + sliding windows)
- **Objective 3**: Validate robustness across cohort and extended wear periods

The Physics: Nonlinear Temperature Reconstruction

$$T = \left[\frac{\beta}{\ln\left(\frac{V_S}{V_M} - \left(1 - \alpha\left(V_0 - 1\right)\right)\right) - \ln\left(V_0 - \left(1 - \alpha\left(V_0 - 1\right)\right)\right) + \frac{\beta}{T_0 + 273.15}} - 273.15\right] \text{°C}$$

MEASURED: Vs/Vm (voltage ratio)

FIXED: α, β (material constants) ← Do NOT drift

DRIFTS: Vo (voltage reference) ← What we estimate

$$\sum_{m=n-N}^{n} \left(T(V_0, V_S[m], V_M[m]) - T_{ref}[m]\right)^2 \quad \text{with respect to } V_0$$

Least-squares estimation: find Vo that best matches reference sensor

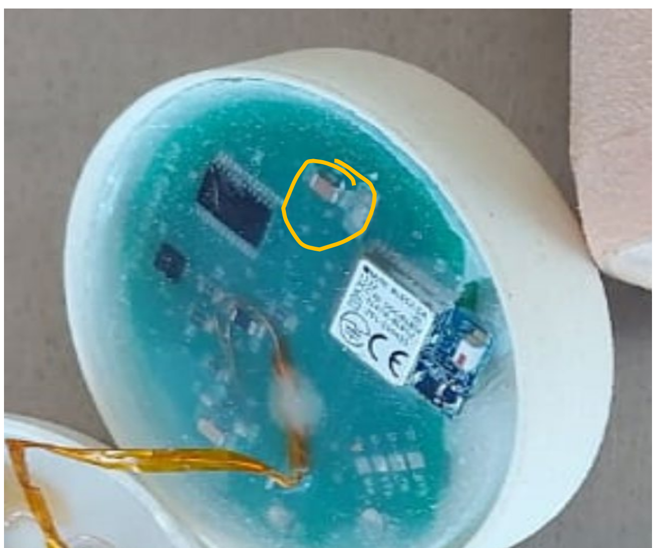
Calibration function [N. Ndzamela, Honours Project 2020]

Experimental Sensor Platform: Dual-Sensor Design

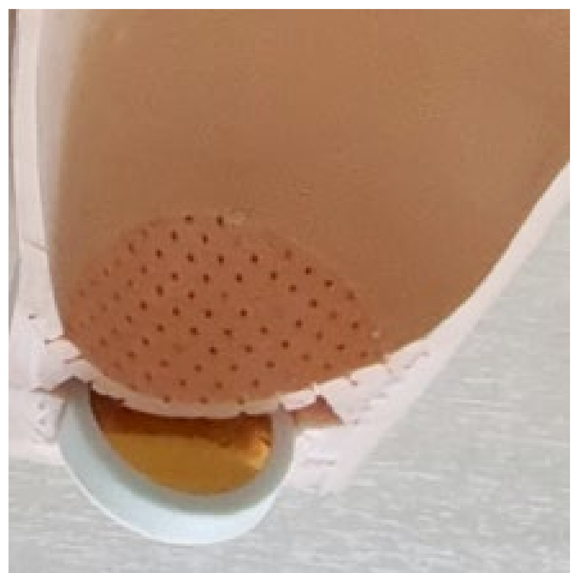
a) 1st generation pod

b) Placement

c) Prosthesis socket



d): Internals of the Pod

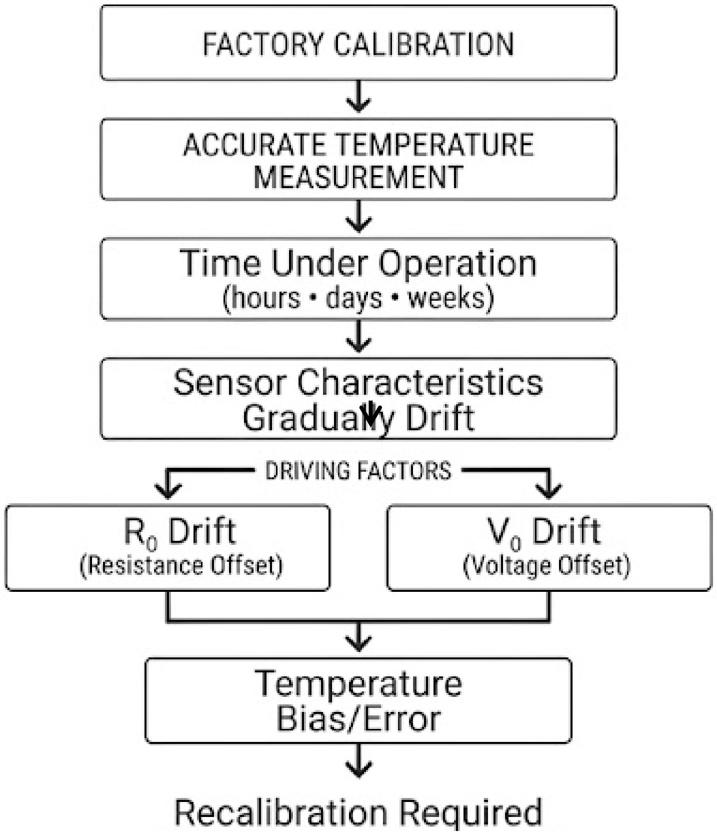


e) Placement

30 sec

f): The new Pod

The Calibration Problem: Why Static Fails

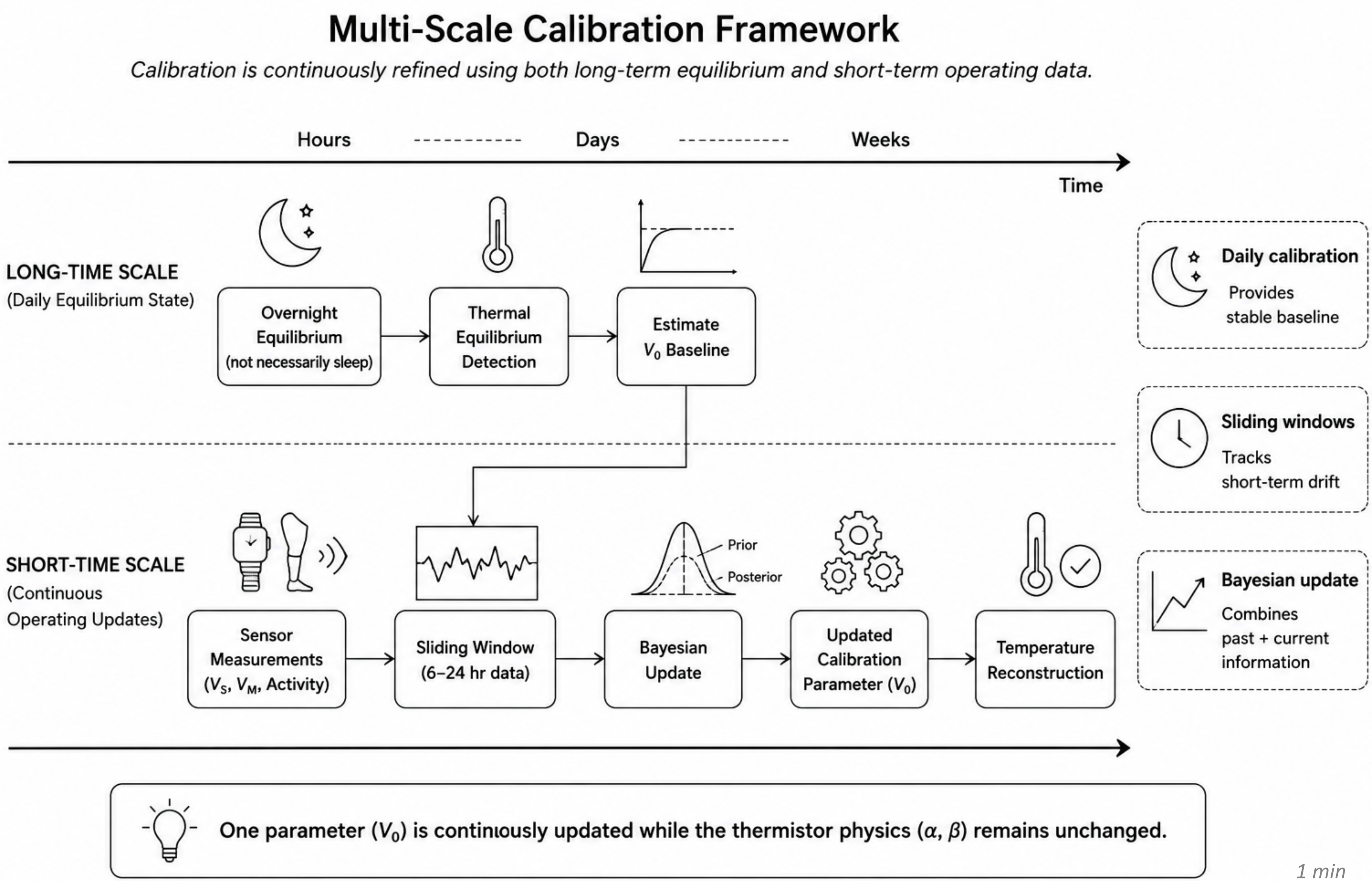


- **Sensor drift occurs gradually due to:**
- Aging of electronic components
- Repeated thermal cycling
- Mechanical stresses
- Environmental exposure
- Long-term sensor degradation

Result

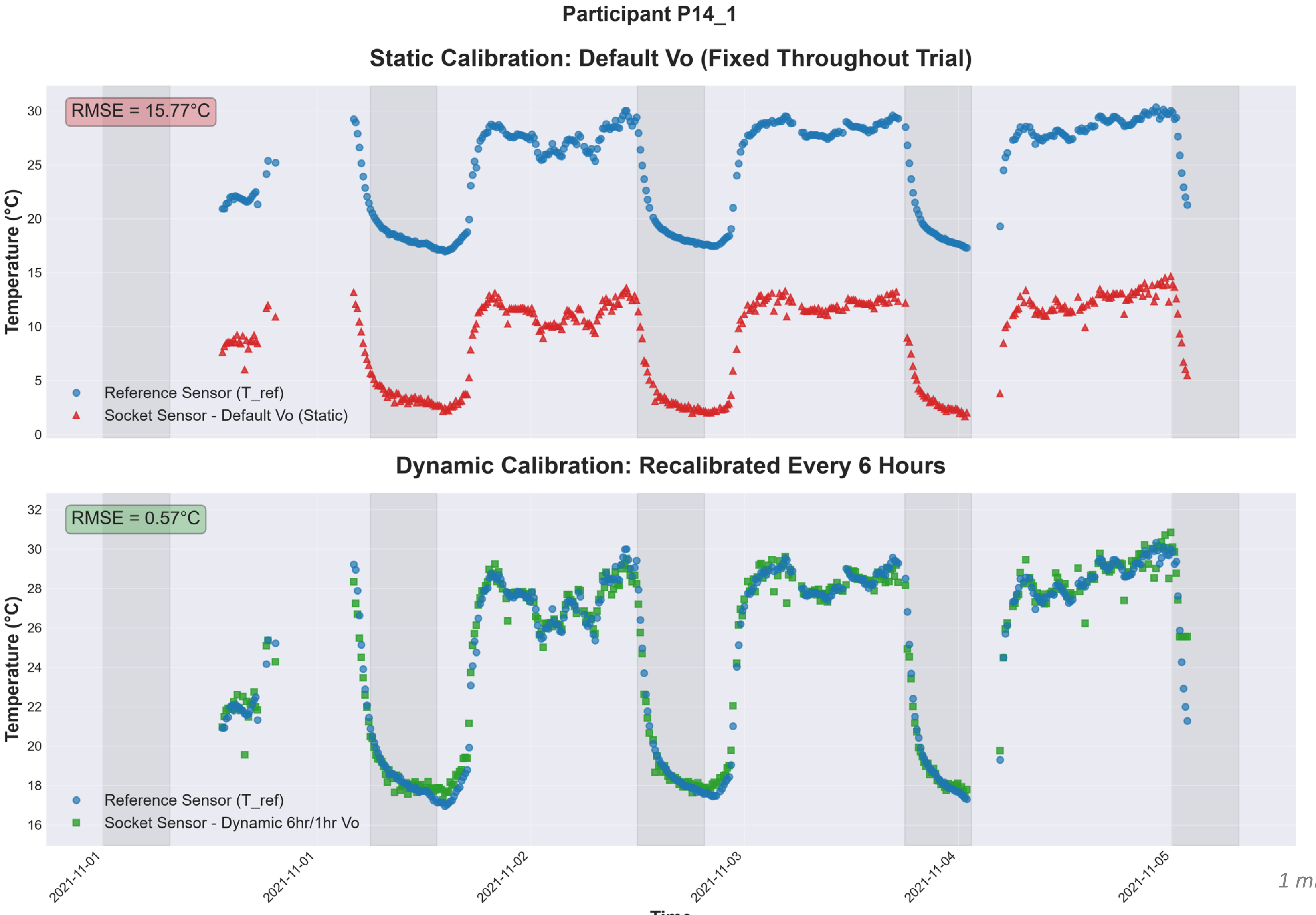
Even when the residual limb temperature remains unchanged, the sensor output gradually deviates from the true value, reducing measurement accuracy.

Multi-Scale Dynamic Calibration Framework



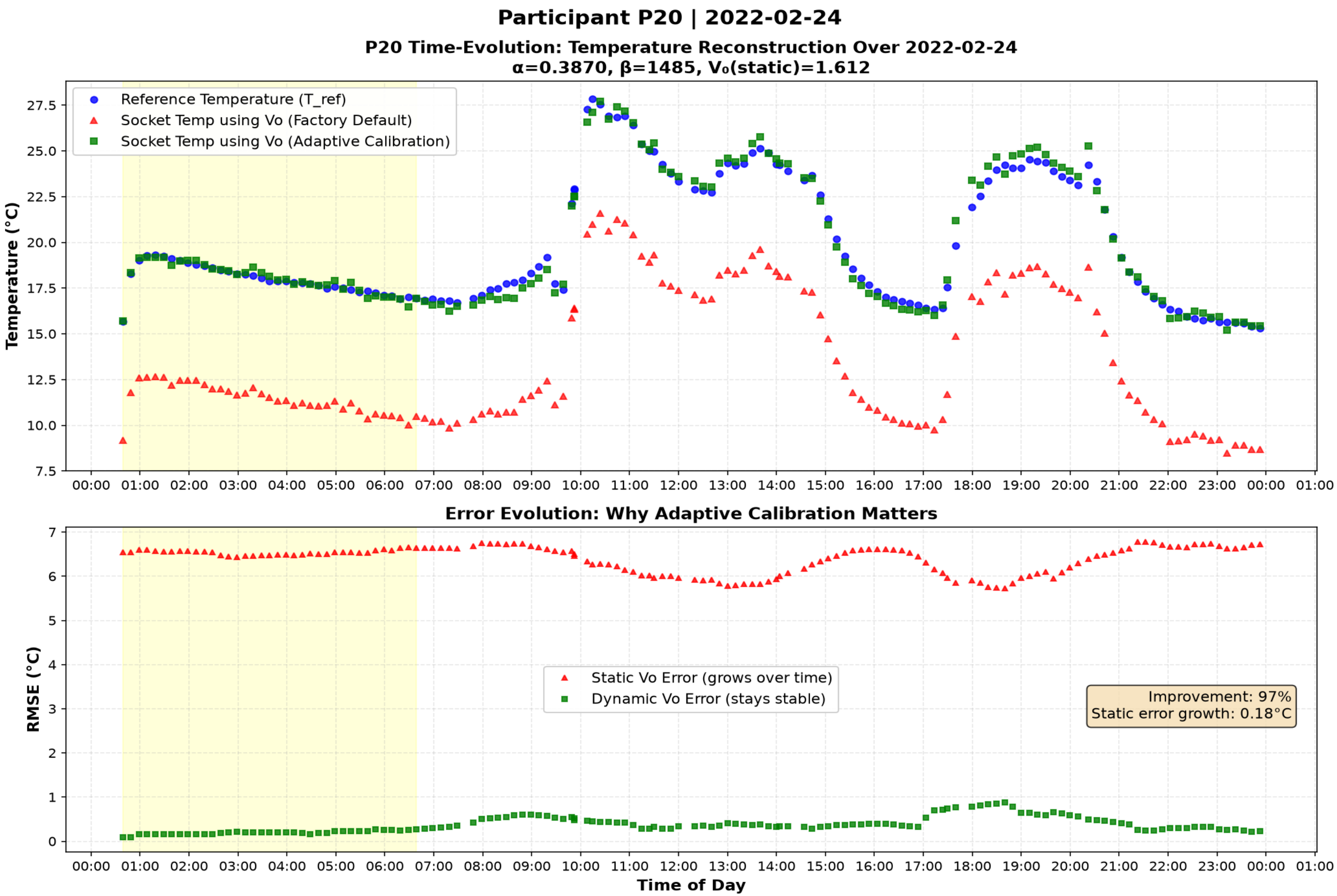
1 min

Results: Adaptive Calibration Performance



1 min

Results: Time Evolution –Temperature reconstruction



Results: Extended Wear (2+ months — Participant P02)

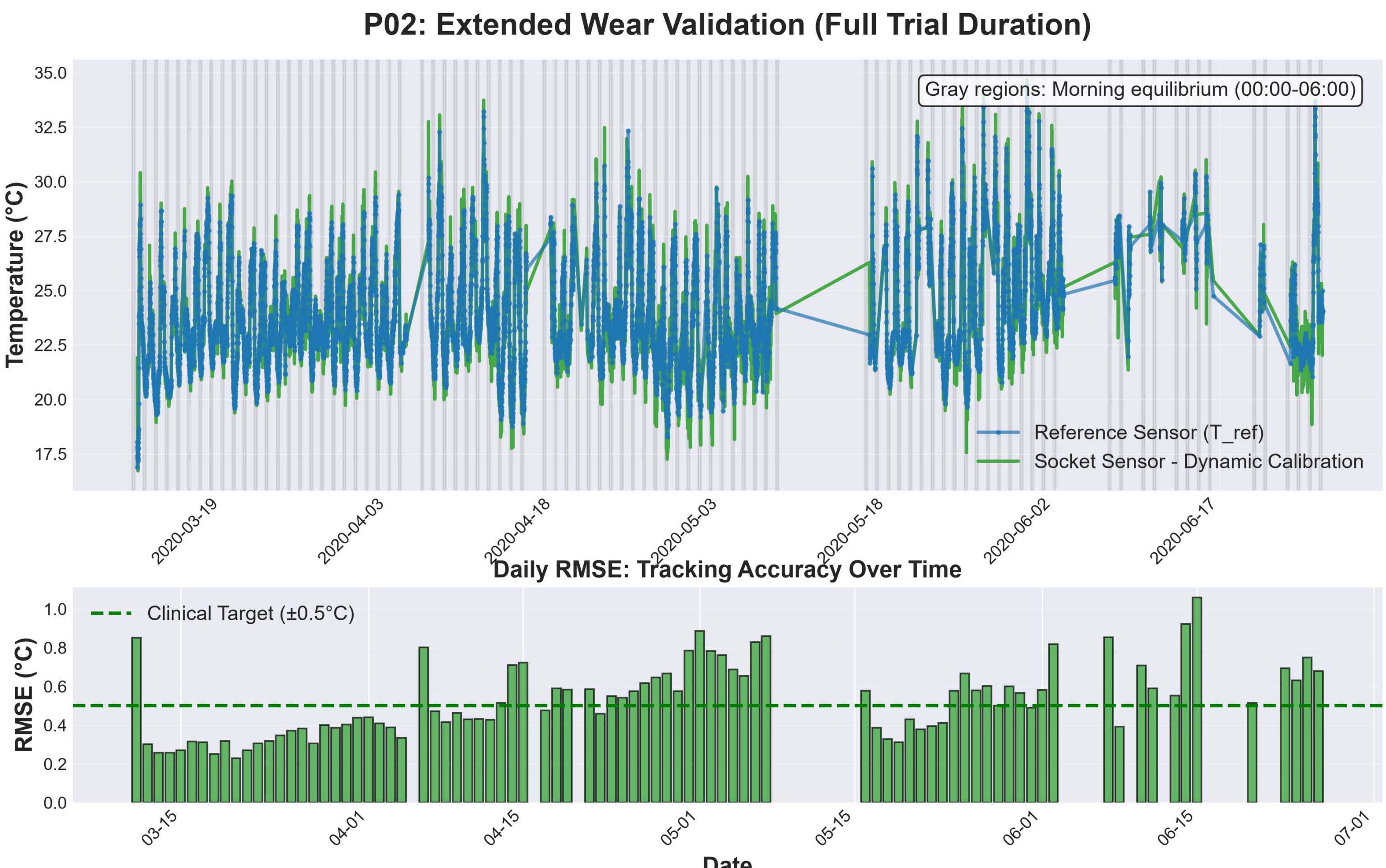
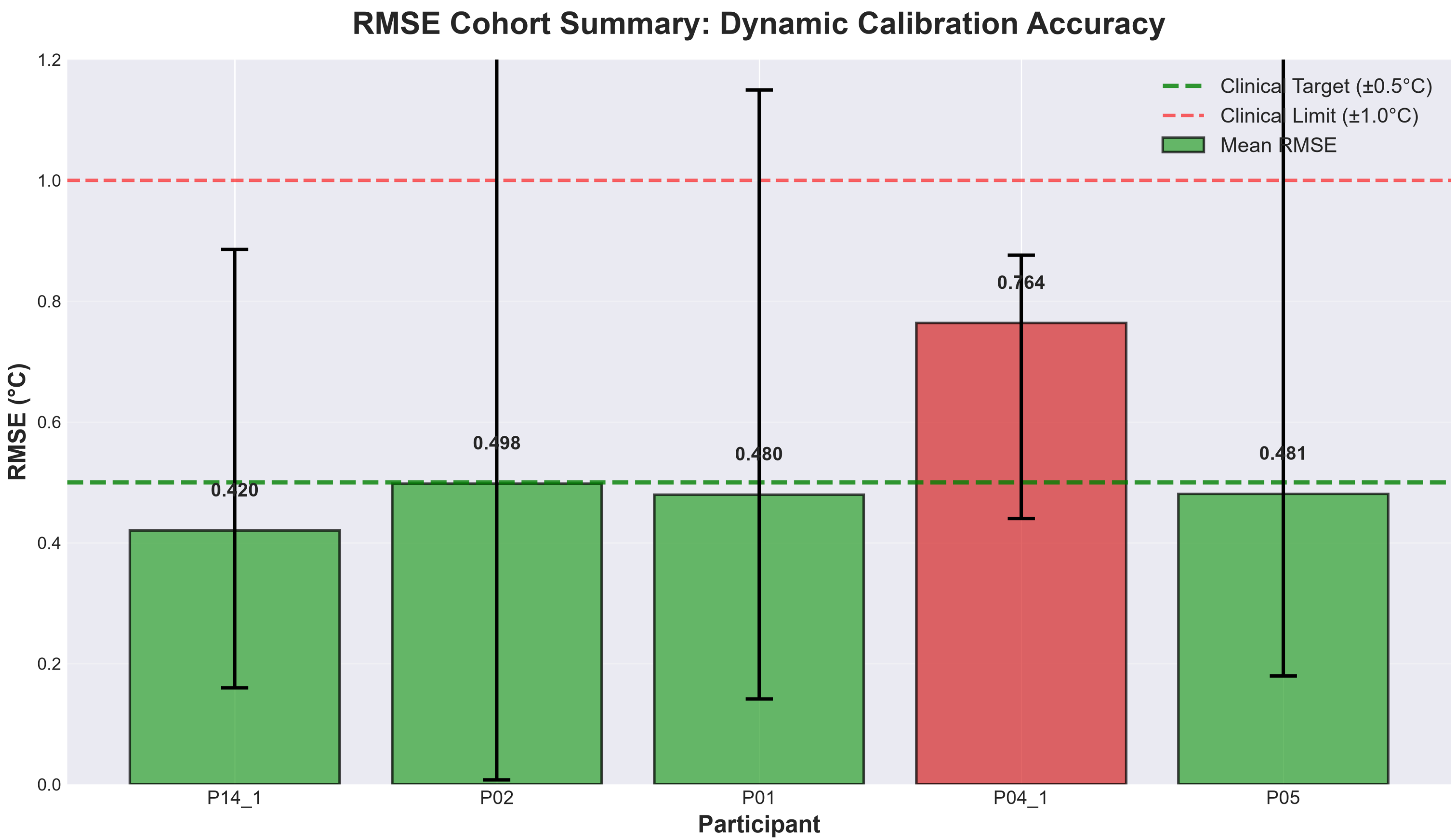


Figure 4: Extended wear validation

- **Full trial duration: blue scatter (T_ref) vs. green line (adaptive T_socket)**
- **Shaded morning regions (00:00–06:00): calibration windows**
- **Consistent RMSE ≤0.7°C throughout extended wear — no degradation**

1.5 min

Results: Error RMSE Comparison (5 Participants

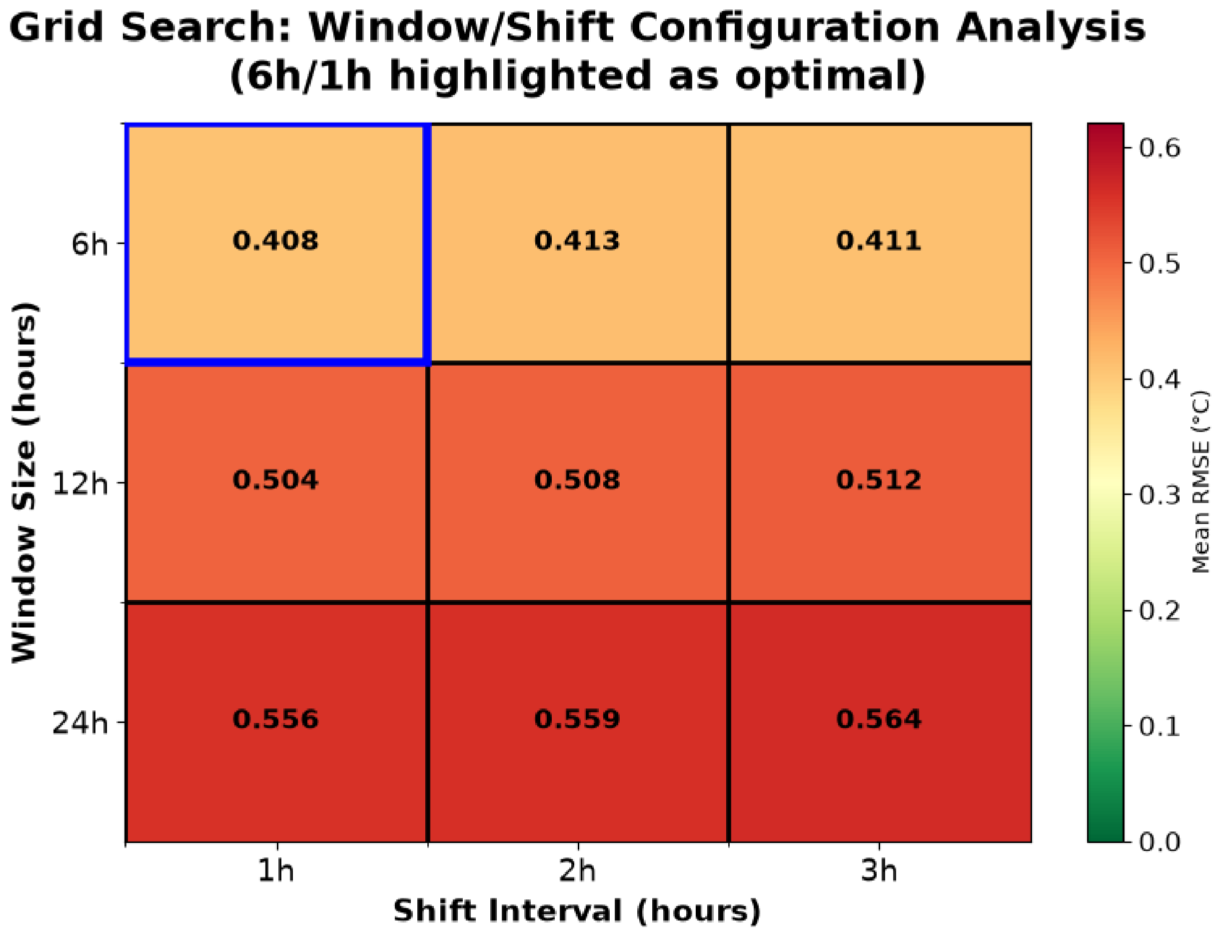


- **Mean RMSE of 0.3–0.5°C across all participants (green zone)**
- **Sub-degree trend detection enables early warning of thermal changes**

1 min

- **Consistent performance: algorithm generalizes across morphologies and wear patterns**

Results: Window Selection Optimization (Grid Search)



- **9-combination grid:** window sizes (6/12/24hr) × shift intervals (1/2/3hr)
- **Cell colors:** green (low RMSE ~0.25°C) → yellow → red (high ~0.7°C)
- **6hr/1hr (highlighted):** optimal empirical trade-off

0.5 min

Discussion: Physics & Clinical Application

- **Six-hour calibration provides the best balance between responsiveness and stability.** Shorter windows are more sensitive to noise, whereas longer windows smooth genuine sensor drift.
- **For the operating lifetime investigated,** sensor drift is dominated by changes in the baseline voltage ($\mathbf{V_0}$), while $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ remain effectively constant as intrinsic sensor properties.
- **Natural overnight calibration** enables continuous monitoring without external equipment or user intervention.
- **Sub-degree accuracy (<0.5 °C RMSE)** is sufficient for monitoring thermal trends associated with prolonged prosthesis wear.

1 min

Take-home Messages

✓ Dynamic calibration maintains clinically useful temperature accuracy (<0.5 °C RMSE).

✓ Only the baseline parameter (V_0) requires periodic updating, while α and β remain stable over the operating lifetime investigated.

✓ The framework can be extended to other long-term wearable temperature sensing applications.

Future Work

- Clinical validation in a larger amputee cohort

30 sec

Thank You

Funding & Support:

- National Nano-Micro Manufacturing Facility (NMMF), implemented by CSIR. Funded by the South African
- Department of Science, Technology and Innovation.

Technical support from project partners & collaborating institutions.

iYunivesithi Walter Sisulu
In pursuit of excellence

PST SENSORS

Ulster University

nano-micro manufacturing facility

science & innovation
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

30 sec