Extensive validation of a real-time time derivative filter for quantized temperature measurements

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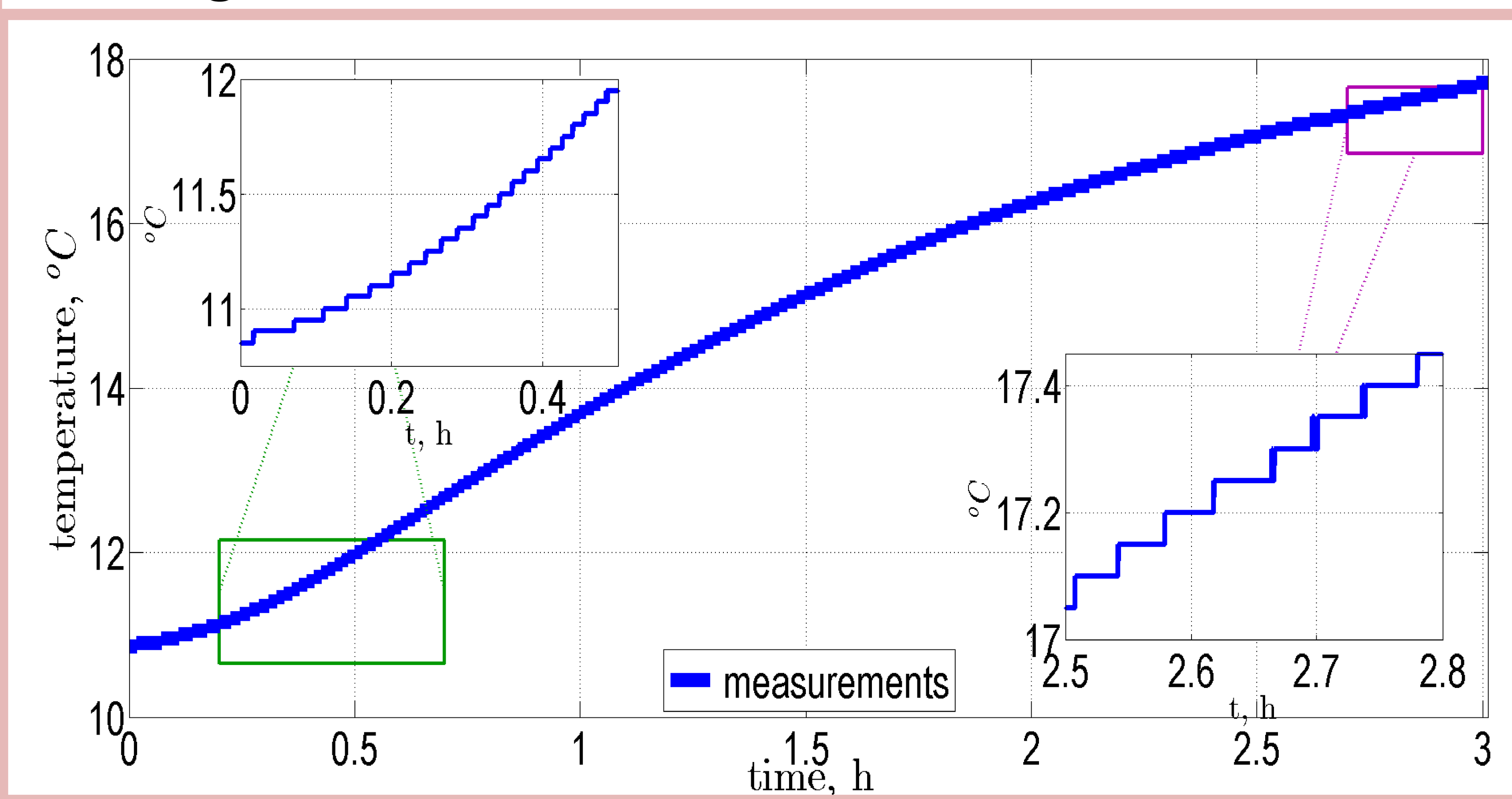
Aims & scope

- Validate a recently developed real-time estimation technique for the temperature time derivative inside a navigation-grade inertial system.
- Overcome specific challenging aspects: measurement quantization, error's time correlation, wide time domain range, real-time implementation.
- A parametric model for a short-term temperature approximation and specific estimation algorithm to determine the model parameters
- Numerically stable finite-impulse-response modification of a conventional Kalman filter applied only on temperature sensor updates.
- Exhaustive analysis of performance over a hundred of experiments with different temperature variation patterns.

Challenges:

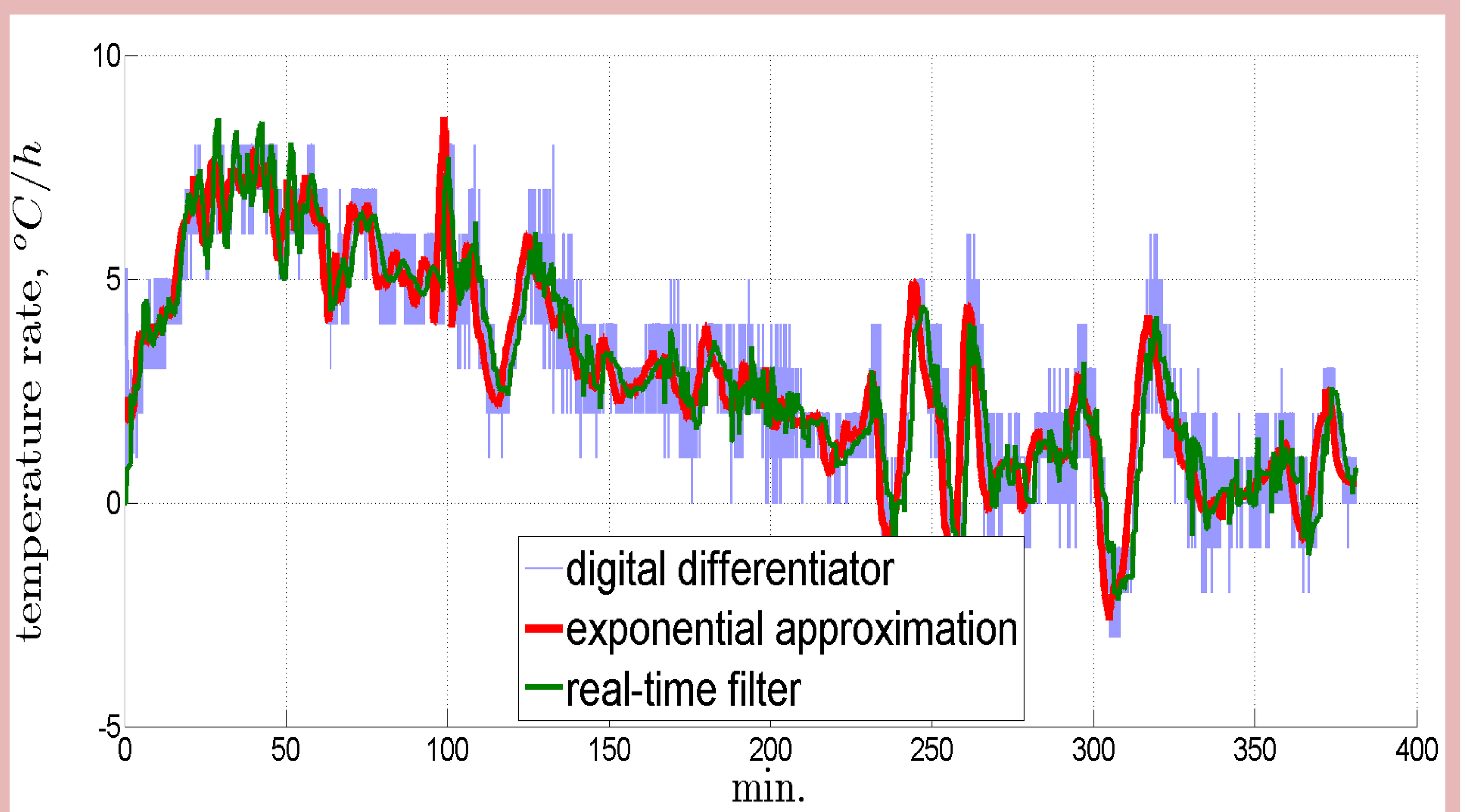


- measurement quantization under slowly changing temperature;
- no white-noise properties in measurement errors;
- wide time domain of thermal processes;
- requirement to obtain estimates in real-time.

Real-time algorithm features:

- exponential prediction model;
- applying measurements only on updates;
- sliding-window modification of the conventional Kalman filter;
- simple to implement in real time on any kind of microprocessor.

Example



1. All three lines lies close to each other;
2. digital differentiator suffers from sudden leaps up 2 ºC
3. real-time filter and digital differentiator inherit visible phase delay up to several mins

Estimation techniques

1. Digital differentiator — the simplest way to estimate derivative

$$\hat{\tau}(t) = \frac{1}{N} \times \sum_{t-T<t_i\le t} \frac{\tau'(t_i)-\tau'(t_{i-1})}{t_i - t_{i-1}}$$

2. Window exponential approximation in post-processing — we use as a reference

$$\tilde{\tau}(t) = \left[\alpha_0(t)+\beta_0(t)\frac{t}{T_0}\right] + \left[\alpha_1(t)+\beta_1(t)\frac{t}{T_0}\right]e^{-t/T_0}.$$

3. Real-time filter — we use as a reference

$$\tilde{\tau}(t) = \alpha + \beta\frac{t-t_0}{T_0} + \gamma e^{-(t-t_0)/T_0}.$$

Results

To validate the proposed approach we have processed over a hundred of records obtained from a system of navigation grade. We compare real-time estimates against post-processing exponential approximation. Summary statistics are listed below.

Average deviation from reference	0.02°C/h
Average absolute deviation from reference	0.9°C/h
Residual standard deviation from reference	1.3°C/h
Average (over the records) maximal deviation	6.4°C/h
Average phase delay	1.9 min

original paper: mdpi.com/1424-8220/20/5/1299