

Dynamic InSAR Time Series Analysis for Near Real-time Monitoring of the Built Environment

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Introduction

- A substantial volume of SAR data becomes available on a daily basis (Fig. 1), yet it remains underexploited in current practice. Conventional InSAR methods are built for batch processing, using static SAR datasets to estimate a predefined static set of parameters, and demand more computation time as observations grow.
- Deformation anomaly detection should be performed in sync with data acquisition and parameter estimation; otherwise, impending infrastructure failures will always be identified too late.
- We propose a new method for DYNAMIC parAMeter estimation of InSAR scaTterer motion in near-real time (DYNAMITE).



Fig. 1. InSAR deformation rate map of the area of interest in Amsterdam, with approximately 3 million observations acquired per day. Most points are stable (green), while blue indicates uplift and red represents subsidence.

Dynamic estimation

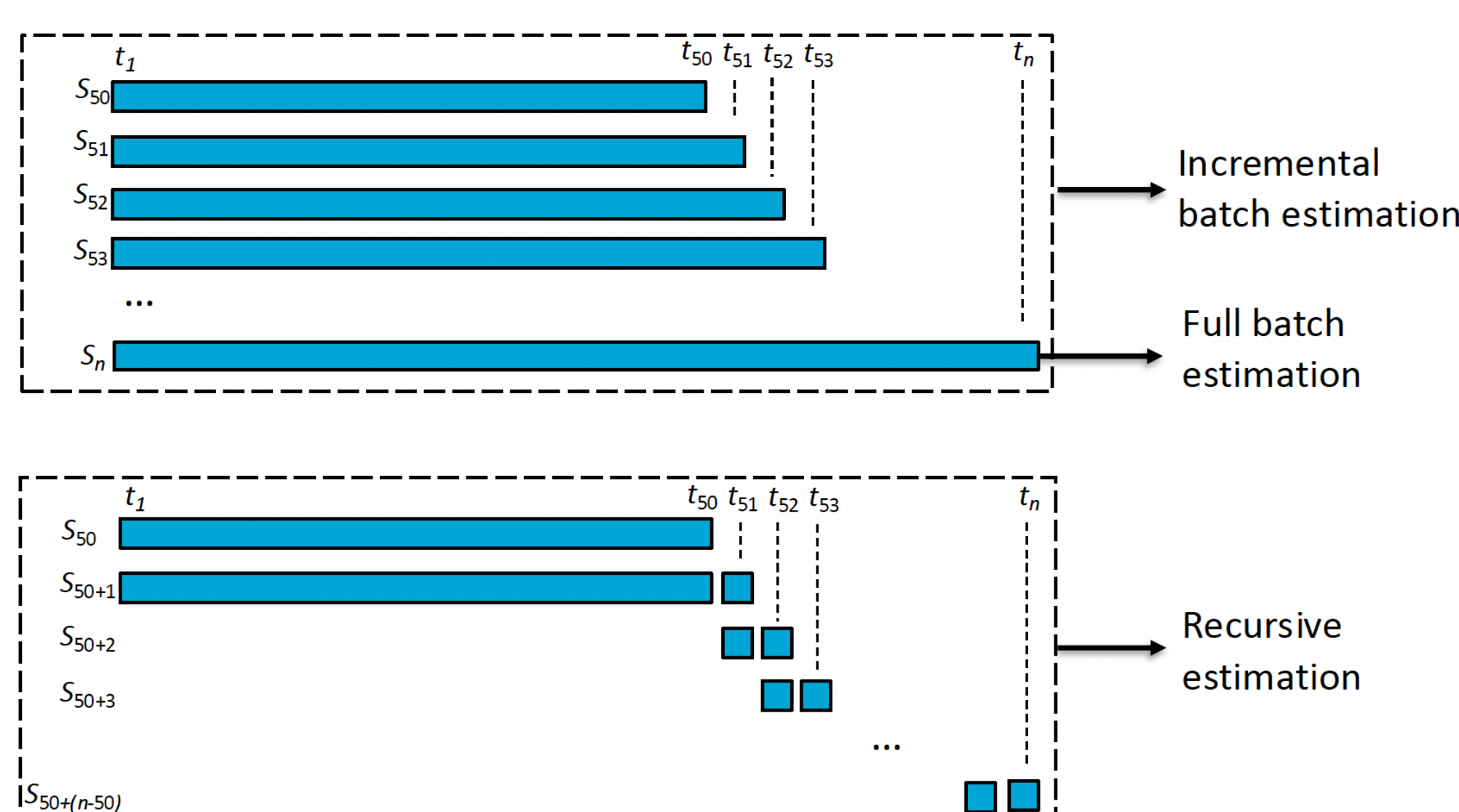


Fig. 2. A schematic diagram of the three estimation methods. Note that recursive estimation updates parameters using only the previous estimate and the current observation, eliminating the need to store past data.

- The instantaneous state vector of unknown parameters (with initial values estimated from an initialization dataset using batch estimation)

$$x_t = [P_t \ v_t \ \Delta H_t \ \eta_t]^T, \quad (1)$$

P_t : the instantaneous LoS position, v_t : the instantaneous LoS velocity, ΔH_t : the cross-range distance, η_t : the thermal expansion factor.

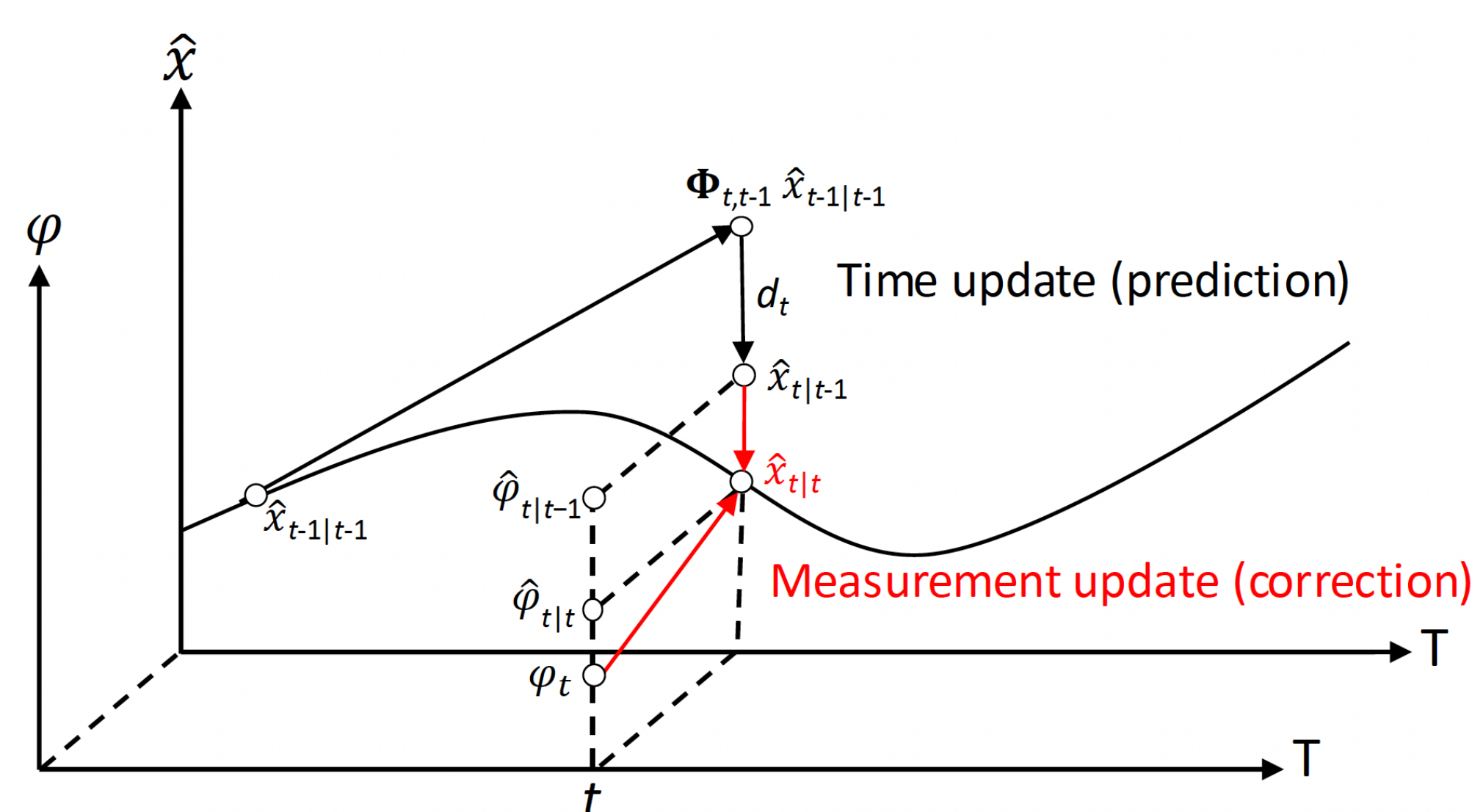


Fig. 3. A schematic diagram of the recursive estimation. x represents a four-dimensional hyperspace with the four unknown parameters of Eq. (1) [1]. φ represents the phase observation between two point scatterers relative to a reference epoch.

Anomaly detection

- As shown in Fig. 4, we implement the testing proposed by [2] using three observations. A data stack of 50 epochs (S_{50}) is processed in batch to obtain an initial estimate at epoch t_{50} . For each observation O_t at epoch t , we perform time updates over the next three epochs to generate predictions P_t , and measurement updates to obtain updated vectors U_t . In total, three time-update and three measurement-update estimates are produced, on which the testing is conducted.

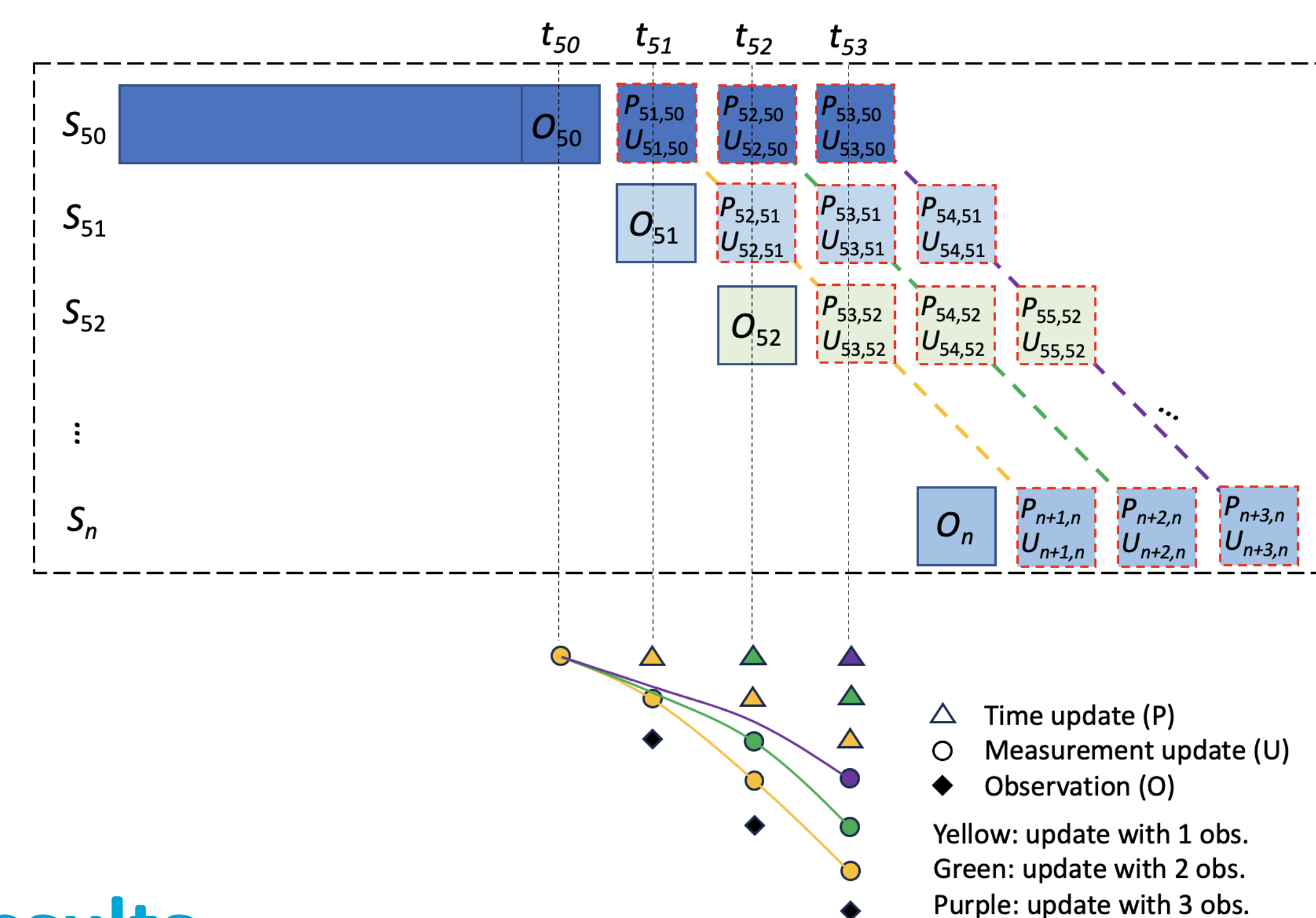


Fig. 4. A schematic diagram of the deformation anomaly detection with recursive estimation using three observations.

Results

- Batch and recursive solution

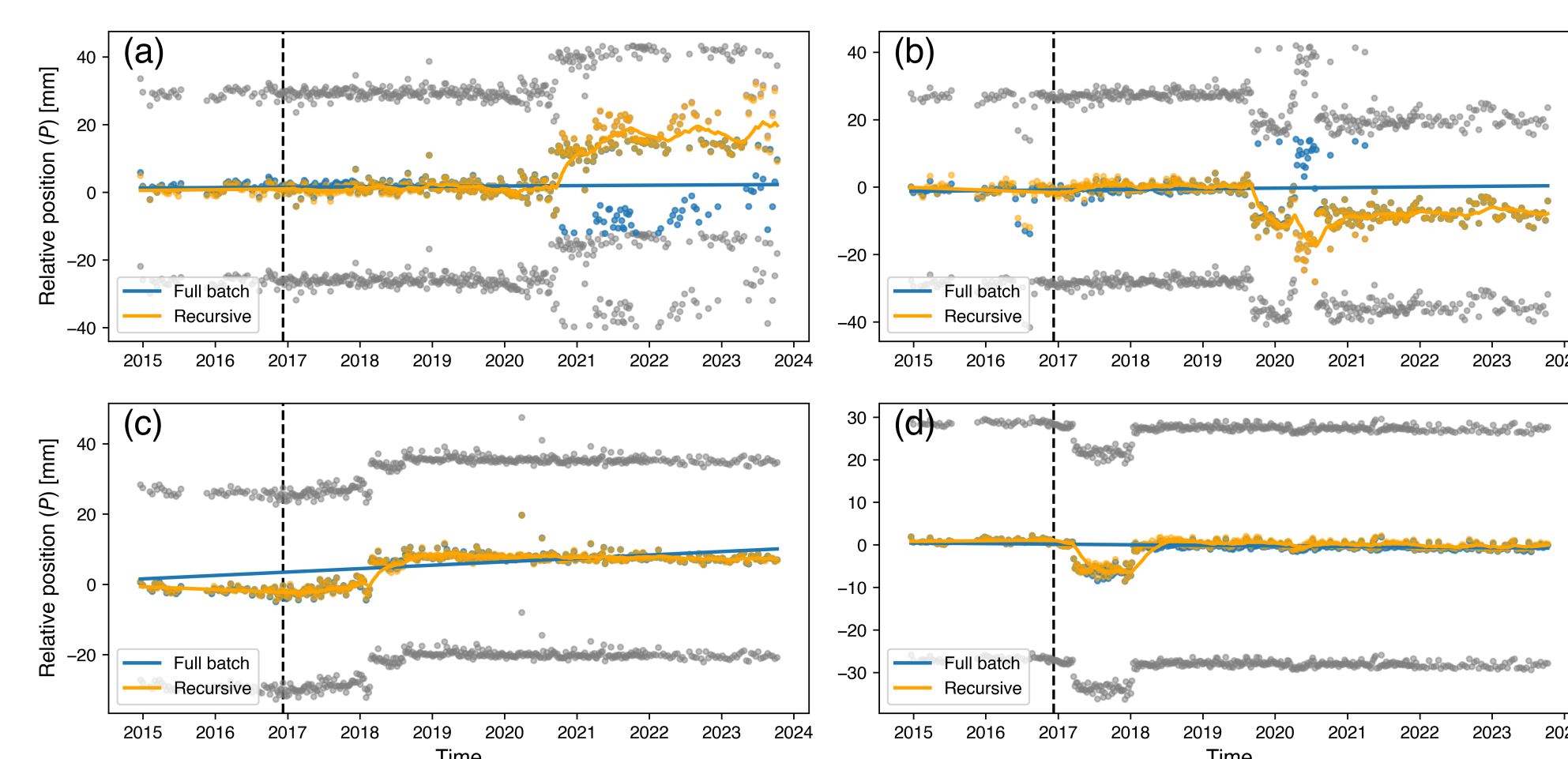


Fig. 5. Estimated relative positions of four point scatterers (a-d) relative to the reference point and epoch using Sentinel-1 data. Batch solution (blue line) reflects the hindsight constant velocity model, while the recursive solution (orange line) better captures the dynamic behavior based on retrospective observations.

- Detected anomalies with multiple observations

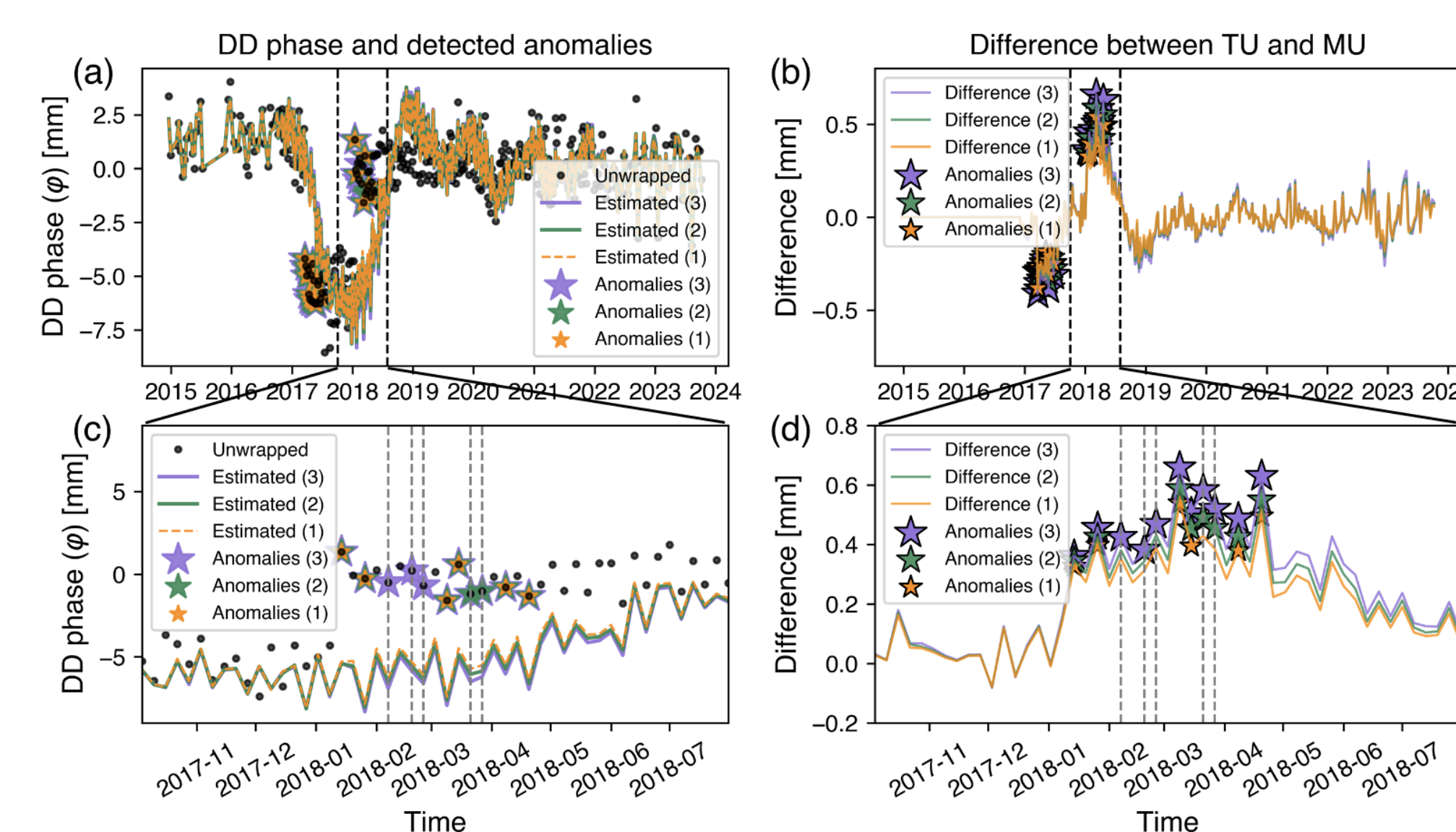


Fig. 6. (a) Estimated phase and detected anomalies after updates with one, two, and three observations, respectively. (b) Differences between time-update (TU) and measurement-update (MU) estimates. (c)-(d) Same as (a)-(b), but for the period between mid-2017 and mid-2018. Gray dashed lines mark anomalies detected with two or three observations but missed by the single-observation update.

Conclusion

A novel method for dynamic InSAR time series analysis which

- performs on par with the batch solution, but captures dynamic behavior better and performs significantly faster;
- enables explicit near real-time monitoring with continuous updates;
- utilizes multiple observations to improve reliability of anomaly detection and reduce the risk of missed anomalies from single observations.

References

- P. J. G. Teunissen, *Dynamic data processing: Recursive least-squares*, 2nd ed. Delft: TU Delft OPEN Publishing, 2024.
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