ETH zürich

Center for Sustainable Future Mobility (CSFM)

Detection of railway track anomalies using interferometric time-series of satellite radar data

Philipp Bernhard[1], David Haener[2], Othmar Frey[1,3]
[1]Earth Observation and Remote Sensing, ETH Zurich; [2]Swiss Federal Railways (SBB), [3]Gamma Remote Sensing

1 Introduction

- The Swiss railway network is among the most heavily used globally, which requires resource-intensive planning, construction, operation, and maintenance.
- **Substructure condition**, affected by moisture accumulation, influences service life and maintenance processes.
- **Early detection** of track anomalies that occur due to moisture accumulation is crucial to significantly extend service life.
- **Current methods**: track geometry vehicles, ground-penetrating radar, and in-situ evaluations.
- **Satellite-based remote sensing techniques** potentially offer a high efficiency for inspecting railway infrastructure including all-day, all-weather imaging with large footprints and high spatial resolutions.

2 Methods

In this study, we propose a new approach to detect track anomalies based on surface displacements retrieved from interferometric time-series of satellite radar data (TerraSAR-X). The effectiveness of this novel methodology is compared to the conventional chord-based measurement technique, which is presently utilized by SBB as an indicator for track anomalies on a network-wide scale. Inspired from the chord-based method's use of relative change measurements, our proposed approach likewise employs variations in surface displacements (based on persistent scatterers), as proxy indicators for potential anomalies.

Persistent Scatterer Interferometry (PSI) Measurements:

- We use satellite observations for deformation measurements that allow to estimate surface deformations on the scale of mm per year.
- We extracts and processed PSI points through several steps (PSI point selection, estimation of height and atmosphere contributions, fit of linear deformation model, error estimation)
- For our data analysis we computed several quantities along moving window including the standard deviation, number of PSI points and their quality as well as strong deformation measurements.

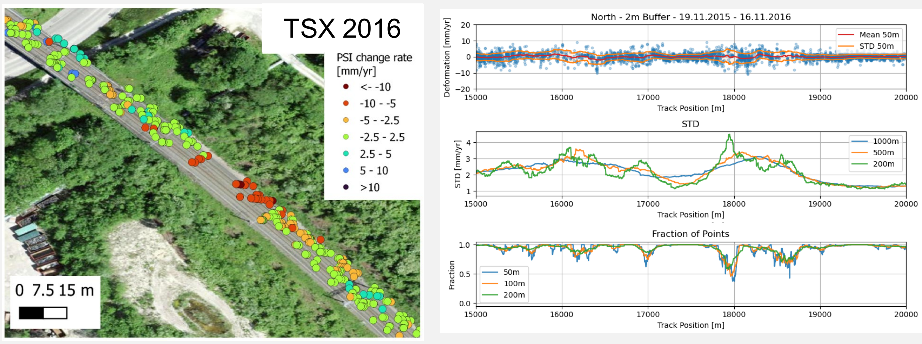

Figure 2 Left: Example region close to Basel of PSI deformation points. In the middle of the image problematic track conditions are indicated by strong deformation measurements as well as a loss of PSI points during processing. Right: 5km of track with PSI points (top), standard deviation along a moving window (middle) and fraction of points with a valid solution (bottom).

Chord-based Measurements (D1 and D2 signal):

- Measures longitudinal height for track condition evaluation relative to the rest of the track position (i.e. it does not refer to fixed points)
- Involves sliding standard deviation of longitudinal elevation signals.

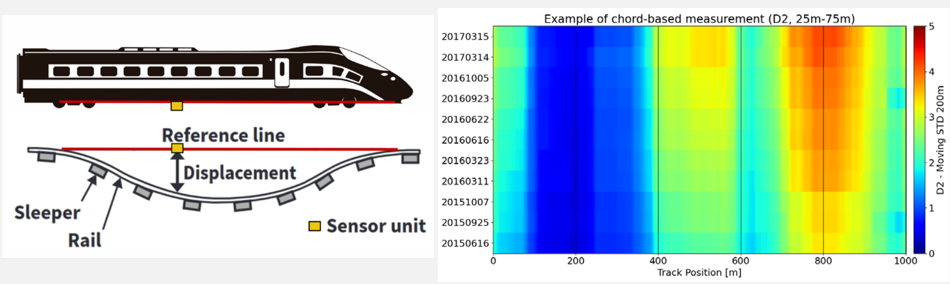

Figure 1 Left: Schematic of the chord-based measurement principle. Right: Example data along the railway track of the moving standard deviation (200m) of the D2 measurement signal that includes variations at the scale from 25m to 75m. Around track position 500 and 800 a worsening of the track condition can be seen.

4 Results and discussion

In a preliminary evaluation, we investigated about 15 km of usable railway track (2 track lines) between Basel and Tecknau (Aargau), where SBB provided chord-based measurement time series from 2012 to 2023. TerraSAR-X time series observations are available from November 2015 to November 2016 and August 2021 to November 2022.
Currently, there is no automated method to extract problematic track parts from chord-based measurements, and we use the same approach as SBB internally, where potential problems are identified by visual inspection of the D1 and D2 time-series (Figure 1, right). To classify problematic track parts from the PSI measurements, we select optimal thresholds based on the Recall, Precision, and associated F1 score.

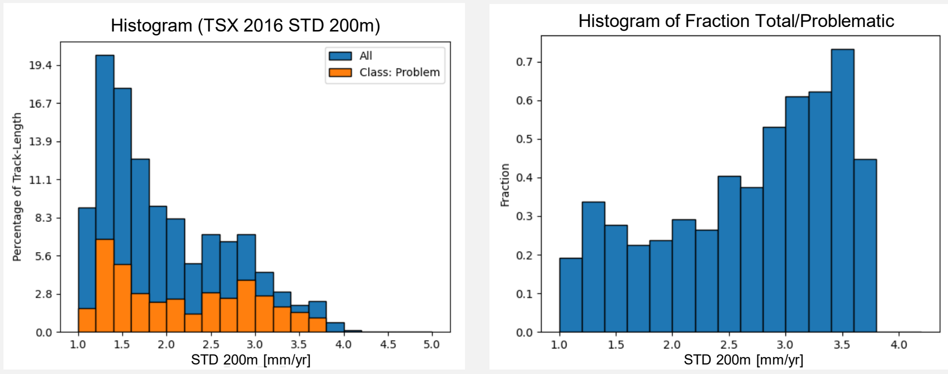

Figure 3 Left: Histogram shown as percentage of total track length of the Standard deviation of the PSI deformation measurements with orange showing parts of the track that are identified as problematic. Right: Fraction of Problematic to the total track length in each bin. An increase towards larger STD values is visible indicating a correlation.

- Problematic track sections, as identified from the chord-based measurement signal, tend to also exhibit larger STD values in the PSI measurements (Figure 3).
- The current state-of-the-art PSI measurements for identifying infrastructure problems primarily focus on substantial deformation measurements (change rates above a certain threshold).
- Incorporating moving STD measurements enhances the identification of problematic track sections (Figure 4).

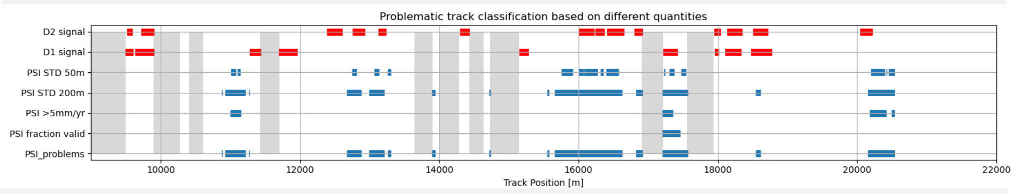

Figure 4: Illustration of a section of the railway track with numerous potential issues based on the chord-based measurements (D1 and D2 signals, shown in red). The data derived from the PSI measurements coincide well with these issues in some areas, but don't reveal potential problems in others. Notably, the quantities calculated from the STD tend to highlight a greater number of problematic track sections.

5 Conclusion and outlook

- Both, satellite-based and chord-based measurement signal only indicate potential track problems and should only be seen as an indicator. No ground truth is available.
- Using the standard deviation of PSI measurements along the track tends to increase the overlap with the chord-based measurement classification compared to only using substantial deformation measurements.
- We are currently working on extending the length of investigated track parts and on developing a classification scheme.

Partner:

amag SBB CFF FFS SIEMENS CSFM