

Technology

ATOMIC CLOCKS ANOMALIES DETECTION THROUGH A MACHINE LEARNING APPROACH

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ABSTRACT

Atomic clocks, both in space and on the ground segments, are crucial for precise timekeeping and navigation. Their applications range from global navigation satellite systems (such as GPS or Galileo) to tests of fundamental physics [1]. It is therefore of paramount importance to promptly detect possible anomalies in atomic clock signals, as such anomalies can affect the accuracy of user positioning and timing.

Traditional approaches to anomaly detection rely on classical algorithms, such as sigma-threshold detectors, cumulative sum (CUSUM) detectors, Kalman filters, Allan variance, and its dynamic variant, the Dynamic Allan Variance (DAVAR) [2]. While effective under specific conditions, these methods may face limitations when applied to complex and dynamic environments.

Recently, studies have highlighted that deep learning techniques, and in particular Temporal Convolutional Networks (TCNs) have the potential to outperform traditional methods in anomaly detection tasks. Deep learning excels at recognizing patterns in complex data, offering a promising avenue to detect anomalies that traditional methods may overlook.

This study has a twofold objective. First, it investigates the application of TCNs for anomaly detection in time-series data, using both synthetic datasets simulating atomic clock behavior and experimental data from atomic clocks onboard GNSS satellites. Second, it aims to explore potential correlations between atomic clock signal and variations in environmental parameters such as temperature and humidity, through a physics-informed machine learning approach that enforces the governing equations and boundary/initial conditions directly within the neural network loss function.

Regarding the first objective, initial tests on synthetic data have demonstrated the capability of TCNs to identify anomalies in controlled environments by capturing temporal dependencies at multiple scales. This result was achieved through a TCN architecture optimized for univariate temporal sequences, using residual blocks with varying dilation rates. However, extending the method to experimental data

introduced new challenges. Models trained on synthetic data failed to capture the complexities of real-world signals from GNSS satellite clocks, which may be affected by periodic behaviors related to the orbital cycle. To address this, the TCN architecture was modified to handle larger sample windows, though this resulted in a trade-off with detection precision.

Despite these challenges, the findings are consistent with other recent machine learning studies, demonstrating the potential of TCNs for anomaly detection in space clocks data. The preliminary results suggest that further exploration and refinement of TCN-based methods could enhance anomaly detection in space atomic clocks, contributing to improving the reliability of GNSS systems.

The core ideas of this study, its scientific goals and recent results, will be presented and discussed at the conference.

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Comments:

Poster presentation preferred