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Self-consistent time series tracking for phase difference and improved density profile reconstruction scheme on the KSTAR reflectometer

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In KSTAR tokamak, frequency-modulated continuous wave (FMCW) reflectometry has been used to measure plasma density profiles with high spatial and temporal resolution. The data analysis process involves extracting time-varying phase differences from the incident swept signal and reflected wave's signal and subsequently calculating profiles through the numerical inversion process. However, tracking a distortion-free and seamless phase difference within the spectrogram, produced by complex wavelet transform (CWT), is challenging because the amplitude inherently changes with the frequency sweeping by the reflectometer components. Also, some clutters are generated from waves reflected at the surrounding structures. Here, we present a novel tracking method for the phase difference in time series. In a CWT spectrogram, phase differences can be computed in two ways: through the imaginary value of complex numbers derived from the CWT or by integrating the instantaneous frequency. If the ideal time series is selected, both ways should yield identical results. However, real-world constraints, such as ambient noise and modulated amplitude, cause inconsistencies in the time series. We treat these discrepancies as a form of the loss function, employing statistical inference to track the most probable time series. Then, to utilize hidden information for limiting possible paths and calculate the phase differences self-consistently across the entire path, our idea is implemented on the concept of hidden Markov models working through the Viterbi algorithm. A comparative analysis between the density profile generated through our developed method and those via existing reconstruction schemes illustrates the potential of our approach to enabling more precise and automated routines, thereby significantly improving the efficiency and accuracy of density profile reconstruction, which is critical for fusion plasma research.

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