

ABSTRACT

Maintaining optimal performance of ultrafiltration systems is critical where the quality and stability of ultrapure water directly impact production yield. Traditional monitoring approaches often struggle to detect early signs of membrane degradation due to the complexity of multivariate sensor data. This study presents a CNN based framework that transforms multivariate flowrate data from 24 ultrafiltration filters into 2D image representations using three encoding techniques: Gramian Angular Summation Field (GASF), Gramian Angular Difference Field (GADF), and Markov Transition Field (MTF). The time series were segmented using a 60-point sliding window, reduced in dimensionality using Piecewise Aggregate Approximation (PAA), and converted into 128×128 image inputs. Two CNN architectures, a Simple CNN and a deeper VGG16 were trained to predict future flowrate values and classify pretreatment operational states. Experimental results show that the combination of GASF and GADF consistently delivered the best performance across both models. Using Simple CNN, GASF+GADF achieved the lowest MSE (0.0365), MAE (0.090), and highest R^2 (0.750). Similarly, under the VGG16 architecture, the same encoding pair achieved even stronger results with MSE = 0.0330, MAE = 0.0882, and R^2 = 0.7665. Despite its higher accuracy, the VGG16 model incurred significantly greater computational cost, up to 10× longer training times (1285.44s for GADF) compared to the Simple CNN (141.27s). These findings suggest that while deeper models may offer marginal accuracy gains, simpler CNN architectures with effective encoding strategies can provide a more practical solution for real time monitoring. Overall, this study demonstrates the potential of image-based time series encoding and CNN regression for early anomaly detection and predictive maintenance in ultrafiltration systems environments with strict runtime constraints.

Keywords: Ultrafiltration (UF) systems, Image-based Time Series Encoding, Gramian Angular Summation/Difference Fields (GASF/GADF), Markov Transition Field (MTF), Convolutional Neural Networks (CNN), VGG16