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SLIDING MULTIFRACTAL ANALYSIS OF AIR POLLUTION TIME SERIES FOR ANOMALY DETECTION AND ENVIRONMENTAL MONITORING

Lyudmyla KIRICHENKO[1], Olha MATSYI[2], Sergiy YAKOVLEV[3]

[1] *Lodz University of Technology, ul. Żeromskiego 116, 90-924 Lodz, Poland*
[1–3] *V.N. Karazin Kharkiv National University, 4 Svobody sq., 61022 Kharkiv, Ukraine*
* ***Corresponding author.*** *Email address: lyudmyla.kirichenko@p.lodz.pl*

Abstract – This study investigates the fractal and multifractal properties of time series of atmospheric pollutant concentrations. It is demonstrated that these characteristics exhibit pronounced self-similarity, long-term correlation memory, and complex scaling behavior. The temporal evolution of fractal parameters serves as a sensitive indicator of both natural and anthropogenic changes in air pollution dynamics, including subtle structural rearrangements that are poorly detectable using conventional statistical methods. A sliding monitoring approach for fractal characteristics is proposed and implemented. The original time series is analyzed in sequentially shifted windows of fixed length with a specified overlap step. In each window, the multifractal detrended fluctuation analysis (MF-DFA) method is applied to compute key metrics: the generalized Hurst exponent, multifractal spectrum width, degree of multifractality, and other measures of scaling inhomogeneity. The resulting estimates form new time series of parameters that reflect the dynamics of the correlation structure and scaling properties of the original data. The analysis results show that anomalous episodes (periods of intense smog, sharp industrial or transport emissions) are accompanied by significant changes in fractal indicators: shifts in the Hurst exponent, expansion or contraction of the multifractal spectrum, and increased degree of inhomogeneity. These changes enable the detection not only of obvious anomalies but also of more subtle structural rearrangements in pollution time series. The obtained results open prospects for applying the proposed approach not only to early detection of anomalous events and comprehensive assessment of atmospheric air quality, but also to optimizing the coverage of environmental monitoring networks. The temporal evolution of fractal metrics can serve as an indicator of zones with increased inhomogeneity and non-stationarity in pollution dynamics, where higher sensor density or resource reallocation is required. This is particularly relevant for modern hybrid systems based on low-cost sensors and IoT technologies. Thus, sliding multifractal analysis contributes to more effective, targeted, and equitable air quality monitoring in urbanized regions.

Keywords – Air pollution; anomaly detection; environmental monitoring; Hurst exponent; MF-DFA; sensor coverage; time series

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