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UrbanAirLab: Data-Driven Calibration of Low-Cost Air Quality Sensors Using Long-Term Co-Location Measurements

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Monitoring air quality in urban areas is essential for assessing environmental pollution and its impact on health and climate, as well as for developing transport and urban planning measures. Legally regulated air quality measurements are based on high-precision reference measuring stations, but their high investment and operating costs mean that their spatial coverage is limited. As a result, small-scale differences in pollutant levels cannot be adequately recorded. Low-cost sensors (LCS) offer great potential here, as they enable dense, continuous and cost-efficient collection of air quality data. At the same time, however, their measurements are often distorted by sensor drift, cross-sensitivities and meteorological influences such as temperature and relative humidity, which limits their direct use for scientific analysis.

We present the UrbanAirLab, a long-term air quality monitoring network on a university campus in Heilbronn (Germany) that will be expanded to cover the city of Heilbronn in the future. The monitoring network is based on self-designed low-cost multi-sensor systems for the continuous recording of NO, NO□, O□, CO, $PM_{2.5}$ and PM_{10} as well as meteorological parameters. The systems include two thermal low-cost dryers as preconditioning method for the PM and the gas sensors inlets. A central element of the concept is the permanent co-location of selected sensor boxes with an official reference measuring station of the Baden-Württemberg State Agency for the Environment (LUBW), which provides reliable comparative data over long periods of time. The UrbanAirLab is also designed as open-source real-world laboratory and serves to train and involve students and schoolchildren in practical environmental observation and data analysis.

The research design follows an empirical, data-driven approach. The aim is to develop and validate machine learning models that reconstruct reference measurements as accurately as possible from the raw data of the low-cost sensors. Data processing is carried out via a scalable pipeline that enables both the continuous storage of time series data and reproducible calibration modelling and evaluation. Various model approaches are being investigated, including multilinear regression, random forest models and gradient boosting methods.

A particular focus is on investigating seasonal effects, the long-term stability of the calibration models and their transferability to identical sensor boxes. The results presented contribute to the further development of data-driven calibration strategies for low-cost air quality monitoring networks and to the evaluation of their potential for scientific environmental observation.