

Abstract of the doctoral dissertation

Determination of gas concentration in wavelength modulation spectroscopy using a method based on artificial neural networks

Keywords: wavelength modulation spectroscopy, gas analyser, concentration, methane, artificial neural networks, WMS, TLAS

Wavelength Modulation Spectroscopy (WMS) is widely used for the detection and concentration measurement of gaseous substances in industry, medicine, environmental protection, and safety applications. In many gas analyser applications, it is essential to develop devices capable of measuring gas concentration with low uncertainty and a short response time. The aim of this doctoral dissertation was to develop a novel method for concentration determination using the WMS technique, characterized by high accuracy, short response time, and the ability to minimize the influence of gas pressure and temperature variations on the measurement result.

As part of this dissertation, a review of the current state of the art in tunable laser absorption spectroscopy, with particular emphasis on the wavelength modulation technique, was conducted. The operating principles and performance of currently used gas concentration determination methods in WMS analysers were analysed. The advantages and limitations of these methods were identified with respect to measurement accuracy, response time, and the influence of gas temperature and pressure on the analyser output. Special emphasis was placed on the application of machine learning in wavelength modulation spectroscopy.

Based on the literature review, the following dissertation thesis was formulated: it is possible to reduce the gas concentration measurement time in WMS analysers while simultaneously minimizing the influence of gas pressure and temperature by employing dedicated artificial neural networks.

To achieve the objective of the dissertation and validate the proposed thesis, a series of research tasks was carried out. An original laboratory methane analyser was developed, and experimental investigations were performed to determine the parameters of both the individual optoelectronic components and the complete measurement system. Subsequently, the influence of gas pressure and temperature variations on the concentration measurement results obtained using the developed analyser was investigated. Furthermore, an original approach for generating large simulation

datasets of spectroscopic signals for machine learning model training was proposed. Based on these datasets, dedicated artificial neural networks for gas concentration determination in WMS systems were developed. In addition, a method for noise reduction in the gas analyser using a dedicated autoencoder was proposed. The developed models were trained and validated using the generated database and subsequently implemented in the methane analyser. The proposed solutions were experimentally evaluated, providing the basis for determining the metrological parameters of the analyser incorporating the artificial neural network models. A concentration determination time below 50 ms, a measurement precision of $3\sigma = 180$ ppb, and a relative measurement error below 5% over a wide range of gas pressures and temperatures were achieved.

In summary, the results obtained for both simulated and experimental data confirmed that the proposed method provides high accuracy while reducing the concentration determination time and simultaneously minimizing the influence of gas pressure and temperature variations on the measurement result. Therefore, the objective of the dissertation has been accomplished, and its thesis has been proven.

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