Using Empirical Mode Decomposition for Increasing The Sensitivity of $^{13}\text{CO}_2$ Detecting in the Human Exhaled Breath by TDLAS Method

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The effective noninvasive diagnostics of gastrointestinal oncological diseases can be successfully carried out by using breath tests for $^{13}\text{C}$ isotope detection in the patient’s exhaled breath ($^{13}\text{C}$ is the part of $^{13}\text{CO}_2$ isotopologue molecule). The analysis of the state-of-the-art results shows that for $^{13}\text{CO}_2$ detecting in the exhaled breath among the most promising there are optical absorption methods which provide both high sensitivity and accuracy of measurements, and also possibility of obtaining on-line results [1,2]. Some of the best results were achieved using the frequency-tunable diode lasers (TDLs) operating in the infrared spectral range near the wavelength of 2 $\mu$m as radiation sources [2].

Thus, earlier, we informed on applying TDL operating in the spectral range near 2 $\mu$m, for on-line detecting of $^{13}\text{CO}_2$ in the exhaled breath [2]. Accuracy of $^{13}\text{CO}_2$ detecting in a mixture with $^{12}\text{CO}_2$ obtained in this paper is 0.8% and was limited by the noise level of the experimental setup. One of the ways to increase $^{13}\text{CO}_2$ detecting accuracy is using different digital signal processing methods which ensure removing considerable part of noise components from the useful signal.

Among those methods, there are particularly different adaptive signal filtering methods as Kalman filter method, Wiener filter method, Empirical Mode Decomposition Algorithm (EMD) and a number of others. In the tasks of high-sensitivity gas analysis with applying absorption spectroscopy method using TDLs operating in near-IR range and mid-IR range, using the EMD method is preferable. It allows efficient reducing of the noise level of non-stationary and non-linear experimental signals.

This paper informs on using EMD method for increasing of $^{13}\text{CO}_2$ detecting accuracy in the human exhaled breath.

InGaAlAs/InP single-mode TDL (Vertilas VCSEL Diodes, Germany) was used as a radiation source. Pump current modulation in the range of 4-9.5 mA and laser diode temperature variations in the range of 20-35°C allowed performing TDL frequency tuning in the range of 4860-4880 cm$^{-1}$. For the fixed temperature of the PDL, the pump current modulation allowed performing frequency tuning in the range of $\sim$6 cm$^{-1}$. TDL generation power was $\sim$1 mW in the all tuning range.

For detecting of $^{13}\text{CO}_2$ we choose P(12) absorption line, in the range of frequency tuning of the used TDL is at most remote from the adjacent R(32) and R(34) absorption lines of $^{12}\text{CO}_2$.

In the course of our experiments, the TDL radiation, modulated by a generator built into the TDL control unit, passed through the multipass gas cell with an optical path length of $\sim$2 m. The cell was filled with expired air probes. The summarized $^{12}\text{CO}_2$ and $^{13}\text{CO}_2$ part was varied from 1.5 to 3.5%, and $^{12}\text{CO}_2$ and $^{13}\text{CO}_2$ concentrations ratio changed in 70-140 range. For measurements, at different pressures, the cell was connected with a high-pressure vacuum pump. The pressure in the cell was measured by vacuum-gauge (ILMVAC GmbH, Germany). The laser radiation passed through a multipass gas cell was registered by an infrared photodetector. The photodetector output signal was received by analogue to digital converter (ADC). Using the earlier described in this paper, EMD algorithm, we carry out the decomposition of an experimental signal into a set of IMFs and residual signal function.

Comparing of results of using EMD algorithm with the result of original signal processing using Fast Fourier Transform filter (FFT), done in [2], was performed by Allan variance method. The minimal error of $^{13}\text{CO}_2$ measurements at using FFT filter method is on the level of $\sim$0.8%. At the same time, using the EMD algorithm led to an almost double increase (0.4%) of measurement accuracy compared to FFT. Thus
the conducted research showed the effectiveness of using the EMD method for increasing the accuracy of 
$^{13}$CO$_2$ content measurement in the exhale breath.

References