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LASER METHANE DETECTION AND CLASSIFICATION USING HARMONIC RATIO FEATURES

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Methane, a potent greenhouse gas, has a global warming potential significantly higher than carbon dioxide. It is a major contributor to climate change, primarily emitted from oil and natural gas operations, agriculture, and waste management processes. Accurate and efficient methane monitoring can help industries identify leaks, optimize processes, and reduce emissions, contributing to a cleaner and safer environment. Given the importance of methane monitoring, the development of innovative devices and experimental methods has become a key focus area. This includes the integration of advanced signal processing techniques, such as those proposed in this research, which aim to enhance the effectiveness of detection and classification methods.

Direct absorption spectroscopy is the simplest form of laser absorption spectroscopy, requiring minimal equipment and offering fast alignment and data interpretation [1]. However, its sensitivity is limited due to uncertainties in measuring the laser output. Wavelength modulation spectroscopy provides higher sensitivity and accuracy but involves more complex signal processing and requires a lock-in amplifier [2].

Wavelength modulation-direct absorption spectroscopy [3] combines the simplicity of direct absorption with the improved sensitivity and noise rejection of harmonic detection, making it an effective method for methane detection and classification.

Figure 1, illustrating the principle of the gas detector system. The figure explains the interaction between the laser radiation and the absorbing methane gas based on the Beer–Lambert law and clarifies the physical origin of each component in the additive harmonic model.

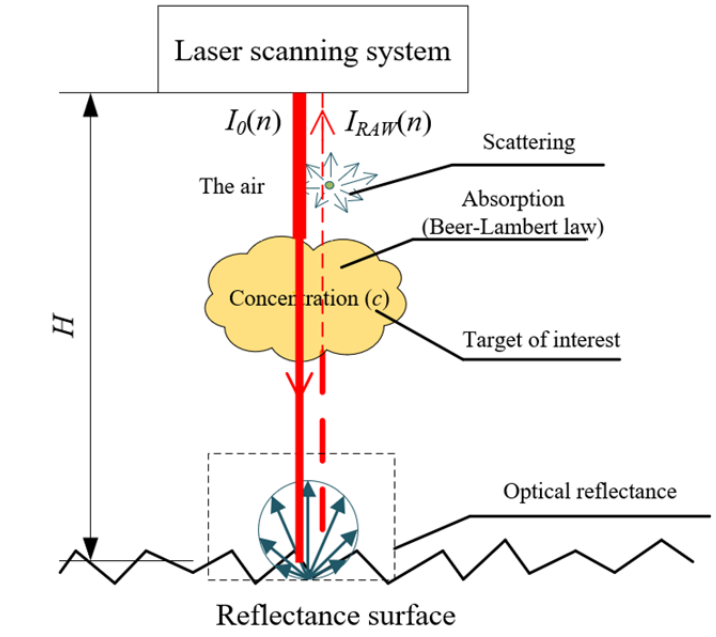


Figure 1. – The principle of the gas detector system

The proposed method (**Figure 2**) for laser methane emission monitoring consists of two parts: detection and classification procedures for the measured absorption signal. These procedures are based on harmonic ratio features and selected threshold values to distinguish between signals with methane presence and absence and to classify the detected signal into low and high noise levels.

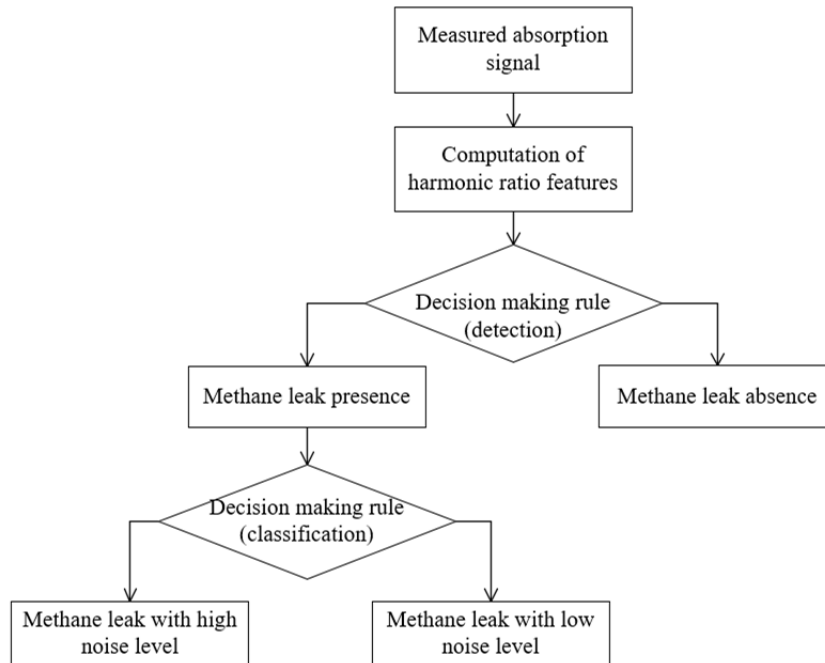


Figure 2. – Block diagram of the proposed harmonic frequency method for laser methane emission monitoring

The first step is removing the $I_{DC}(n)$ component of the measured absorption signal by the Z-score normalization operation. The following spectral harmonic ratio features are computed: 1) an even-to-odd harmonic ratio $EOHR(K_H)$, 2) a spectral centroid SC , 3) a harmonic to noise ratio $HNRF$ and 4) a proposed root-mean-square base harmonic ratio $RMSBHR(K_H)$ [4].

The laser dataset obtained by the experimental and provided by the department of remote control systems consists of the measured absorption signal with the following parameters: a sampling frequency of $6.3 \cdot 10^6$ Hz, a base frequency of 10 kHz, a resolution of 24 bits per sample, a data volume of 376 signals, and signal lengths ranging from 32768 to 1400000 samples. The laser dataset received from the experiment was divided into two classes: the training dataset containing 16 methane signals and the validation dataset containing 100 methane signals with a low noise level signal, 100 methane signals with a high noise level and 100 generated signals without methane with signal-to-noise ratios ranging from 37.47dB to 63.70dB.

y using the validation dataset.

Table shows results of the detection and classification accuracy using the validation dataset.

Table – Methane detection and methane signal classification accuracy

Task	Accuracy
Detection	99.67%
Classification	77.0%

It follows from y using the validation dataset.

Table that, the methane detection accuracy is very high (99.67%), indicating the method is highly reliable in identifying the presence of methane. However, the classification accuracy is significantly lower (77.0%), suggesting that while detection is robust, distinguishing between different methane signal classes.

References

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