TECHNICAL SCIENCES

INTEGRATION OF AN AMMONIA SENSOR INTO VIDEO ENDOSCOPY FOR EARLY DETECTION OF HELICOBACTER PYLORI INFECTION

Sabirov R.
PhD candidate in Medical Technology Engineering
Azerbaijan State Oil and Industry University, Azerbaijan, Baku.
ORCID: 0009-0008-5436-6047
https://doi.org/10.5281/zenodo.18840590

Abstract

The early diagnosis of gastrointestinal pathologies is of great importance in clinical practice. Currently, endoscopic diagnosis is carried out using visual and invasive biopsy techniques. These methods have limitations in detecting early functional and metabolic changes. Particularly in Helicobacter pylori-associated gastritis, metabolic abnormalities develop before morphological changes. As a result, false-negative results can occur during the diagnosis of H. pylori infection.

This study proposes a novel endoscopic detection procedure using an ammonia (NH_3) sensor into endoscopic systems for the early and non-invasive detection of H. pylori infection. A scientific justification of the sensor selection is presented based on the clinical literature. A design of the distal tip of the endoscope, which facilitates real-time measurement of the concentration of ammonia, is also presented. It is ensured that the integration of the sensor does not affect the optical and mechanical functionality of the endoscope. The measured ammonia levels were normalized and classified into clinical risk categories, and the raw sensor data was converted into a digital diagnostic indicator. The proposed framework of methodology increases the level of objectivity of diagnostics, minimizes unnecessary random biopsies, and offers a scientific basis for the development of artificial intelligence-based multimodal endoscopic diagnostic systems.

Keywords: Ammonia sensor, video endoscopy, H. pylori infection.

Introduction

The early detection of gastrointestinal pathologies is a problem of vital importance in clinical practice, and one of the most common methods used for their detection is endoscopy. However, the traditional methods of endoscopy are based on the evaluation of the morphological characteristics of the mucosa using white light endoscopy (WLE). Besides these methods, advanced methods like Narrow Band Imaging (NBI) and Flexible Spectral Imaging Color Enhancement (FICE) are used for the precise evaluation of vascular structures [1, p. S16-20].

Although research has proven that the combined application of these imaging techniques can enhance the diagnostic accuracy of early-stage gastric cancer, the methods currently employed are based on subjective visual interpretation and often need verification through random or selective biopsy samples [2].

Early-stage pathological changes are not clearly visible and may lead to false negative results. The pathogenesis of gastrointestinal pathologies at an early stage, particularly in the context of Helicobacter pylori-associated gastritis, is closely related to complex metabolic and biochemical changes occurring in the mucosa. As studies have shown, H. pylori infection alters the composition and metabolic activity of the gastric microbiota, leading to the formation of specific metabolic profiles that maintain chronic inflammation. Although thermal and metabolic imbalances are observed at the tissue level at this stage, structural and morphological changes generally do not reach a clinically significant level [3].

At this stage, one of the major limitations associated with endoscopic diagnosis is related to the fact that functional and metabolic changes develop prior to structural changes. Current imaging technology used in endoscopic procedures cannot directly detect increased levels of metabolic activity, biochemical changes, and imbalances in functions. As indicated in the literature, despite increased levels of metabolic activity at the tissue level in early stages of inflammatory and precancerous conditions, these conditions are not clearly visible in images at the macroscopic level and depend on subjective interpretation by the operator [4].

To summarize, pathological processes such as high-grade inflammation, dysplasia, and early neoplastic transformation are characterized by functional and metabolic abnormalities. However, there are certain limitations of the present endoscopic systems in the detection of functional abnormalities in real time. Hence, the process of diagnosis involves biopsy procedures, which increase the cost of the procedure, time taken for the procedure, and discomfort for the patients.

The purpose of the study

In modern endoscopic devices, the basis of the diagnostic process is the interpretation of images captured by the CCD and CMOS-based visual sensor. While the approach is successful in the detection of changes in the structure and morphology of the mucosa, the approach is lacking in the assessment of functional and metabolic disorders that occur in the early stages of inflammatory and infectious diseases. Specifically, in the early stages of gastritis associated with Helicobacter pylori infection, an increase in metabolic activity occurs before structural changes, there is an increase in metabolic activity before the development of morphological changes, and the diagnostic process based only on visual sensor data can lead to false negative results.

This situation highlights the need for additional sensor technologies that complement visual sensors in endoscopic platforms and can evaluate functional biomarkers in real time.

The goal of the present research is to design and scientifically verify a conceptual diagnostic method based on an ammonia (NH_3) sensor integrated into endoscopic devices for early detection of Helicobacter pylori infection. The study presents the selection of an ammonia sensor, a constructive design solution for its integration into the distal end of the endoscope, and a normalization model for NH_3 concentration based on normative ranges of clinical values. The suggested method is intended to create a methodological and technological basis for the use of functional biomarkers in endoscopic devices.

Modern Endoscopic Diagnostic Systems

Standard white light video endoscopy (WLE) is the most commonly used method in clinical practice. This method enables real-time imaging of the gastrointestinal mucosa using matrix sensors. Figure 1 shows the CCD (Charge-Coupled Device) elements of a typical video endoscope used in clinical practice.

Figure 1. Matrix sensors of video endoscope.

Ulcers, bleeding, and neoplastic lesions are very effective in the detection of macroscopic pathology. However, the diagnostic potential of WLE is basically restricted to the visual assessment of surface morphology and lacks sufficient sensitivity to identify early inflammatory, structural, and functional alterations. In particular, in the early phase of Helicobacter pylori infection and in the initial phase of low-grade dysplasia, the mucosal alterations are not visually specific, which may cause difficulties in the diagnosis and result in a potential false-negative result [5]. This limitation directly impacts to the problem of false negative results and leads to a greater reliance on random or protocol biopsy sampling, which is known to be prone to sampling error. Because biopsies are usually taken from visually suspicious regions, functionally active but visually normal regions may be overlooked. Clinical data suggest that a substantial number of precancerous gastric lesions and early inflammatory changes are overlooked during routine WLE evaluations, especially in patients with mild or patchy mucosal disease [6, p. 141-150]. Thus, WLE alone is not adequate for the early detection and risk stratification of gastric pathologies.

Narrow Band Imaging (NBI), Flexible Spectral Imaging Color Enhancement (FICE), and i-Scan spectral endoscopy use specific wavelengths of light to enhance the visualization of tissue and vascular structures. These techniques enable more accurate visualization of mucosal microarchitecture by taking into account the optical absorption of hemoglobin. Although spectral endoscopy is effective for the detection of dysplasia and neoplastic lesions, it does not offer any direct functional and biochemical information and is also operator-dependent [7].

Matrix Sensors (CCD/CMOS)

The technological basis of modern endoscopic imaging systems is semiconductor image sensors of the CCD (Charge-Coupled Device) and CMOS (Complementary Metal-Oxide-Semiconductor) type [8]. Figure 2 illustrates a macroscopic view of the active working surface and internal structural layer of a CCD image sensor.

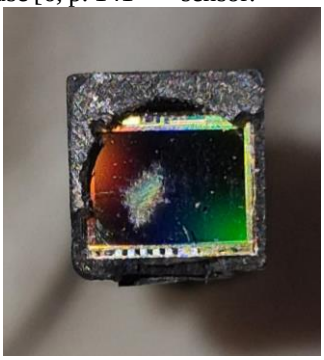

Figure 2. Appearance of the active semiconductor layer of the CCD image sensor

CCD (Charge-Coupled Device) and CMOS (Complementary Metal Oxide Semiconductor) sensors are used in endoscopic systems for the optical imaging of the structural and morphological characteristics of the mucosa in endoscopic systems. Although CCD sensors are characterized by a high signal-to-noise ratio high homogeneity of the images, their high power consumption is a disadvantage, and the sequential nature of the readout process can be a limitation for real-time processing. On the other hand, the advantages of the use of CMOS technology, including faster data transfer, low power consumption and compact system design because they have integrated readout electronics at each pixel level. For this reason, the vast majority of modern video endoscopes use CMOS-based image sensors [8].

However, the fundamental limitation of both sensor technologies is that they operate on the basis of optical information only. Both sensors are incapable of detecting biochemical and metabolic changes within the tissue, and the early stages of inflammatory processes and disorders of function, related to Helicobacter pylori, often lack visual specificity.

Therefore, though CCD and CMOS-based imaging systems have proven to be effective for detecting structural changes, there is a limitation with regard to obtaining functional and metabolic information. This creates a scientific and technological rationale for the integration of other functional sensors, particularly those with the capability of detecting real-time metabolic biomarkers like ammonia.

Thus, the use of ammonia sensors in endoscopic devices appears to hold promise for the early non-invasive detection of Helicobacter pylori infection. The increase in the local concentration of ammonia in the gastric lumen, which is caused by the high urease activity of the bacteria, can act as an indicator of the presence of Helicobacter pylori [9]. Detecting metabolic changes in the early stages may enable earlier diagnosis of infection, allowing diagnostic decisions to be made at an earlier stage.

In addition, determination of the levels of ammonia not only indicates the presence or absence of pathogens, but it also offers supplementary information regarding the functional condition of the tissue and metabolic responses to pathological processes. Obtaining this functional information in real time can enhance the informative value of endoscopic examination and partially eliminate the subjectivity of visual assessment. Early detection of functional conditions reduces the need for random tissue sampling, minimizes the overall procedure time, and reduces patient stress from an invasive procedure. All the above-mentioned advantages allow us to evaluate the use of ammonia sensors in endoscopic diagnostic systems as a viable and scientifically justified approach. Therefore, inclusion of ammonia sensors into endoscopic systems is a promising approach for early, accurate, and functional diagnosis and solves one of the main problem areas of the research.

Methods

Various clinical studies have shown that ammonia concentrations in gastric juice are high and that this is harmful in cases of H. pylori infection. It has been found that the concentration of ammonia in patients infected with H. pylori is significantly higher than that in patients who are not infected (5.58 ± 2.69 vs. 2.00 ± 1.49 μmol/L). These indicators have been statistically correlated with H. pylori density, gastritis activity, and gastric pH, demonstrating the effectiveness of the ammonia measurement device [10, p. 205].

Similarly, other studies have also shown that ammonia concentration in gastric juice is significantly increased in H. pylori-positive patients and that this indicator can be used as a diagnostic biomarker for infection. This confirms the pathophysiological importance of ammonia production.

The selection of the ammonia sensor in endoscopic studies was based on scientific criteria grounded in clinical pathophysiology and technical measurement requirements. As shown in the literature, during Helicobacter pylori infection, local ammonia production occurs in the gastric mucosa as a result of the bacterium's high urease activity, and this condition is observed with significantly higher NH_3 concentrations compared to uninfected cases. Clinical and experimental studies have shown that ammonia levels in the gastric environment increase during infection and can vary between approximately 10-100 ppm; this makes ammonia concentration an important functional and biochemical diagnostic marker [10, p. 205].

For this reason, an electrochemical ammonia sensor that is able to measure ammonia concentration at low levels was chosen for the study. The capability of the ammonia sensor to detect ammonia increases at the 1 ppm level enables the early detection of the increase in ammonia levels due to bacterial metabolism.

Sensor design

This section will present the proposed design of the distal tip for the sensor application in the integration of the sensor with the endoscopic system, together with the scientific basis of the sensor application. The major objective of the proposed sensor integration with the endoscope system is to develop an endoscope system that can perform real-time, minimally invasive, and non-invasive measurements of the local concentration of the ammonia present in the gastric mucosa, while the imaging capabilities of the endoscope system will not be compromised. Figure 3 shows the proposed design of the distal tip for the integration of the sensor with the endoscope system.

The main aim of the suggested integration of sensors is based on the development of an endoscopic diagnostic system that facilitates the real-time, minimally invasive, and non-invasive measurement of the local concentration of ammonia (NH_3) in the gastric mucosa. The acceptance of NH_3 as a metabolic biomarker of H. pylori infection is the scientific basis for the suggested sensor-based system [11, p. 51-57].

Hence, the increase in the level of ammonia in the gastric environment is detected due to the high urease activity of H. pylori, thereby providing important diagnostic information for the early detection of H. pylori infection.

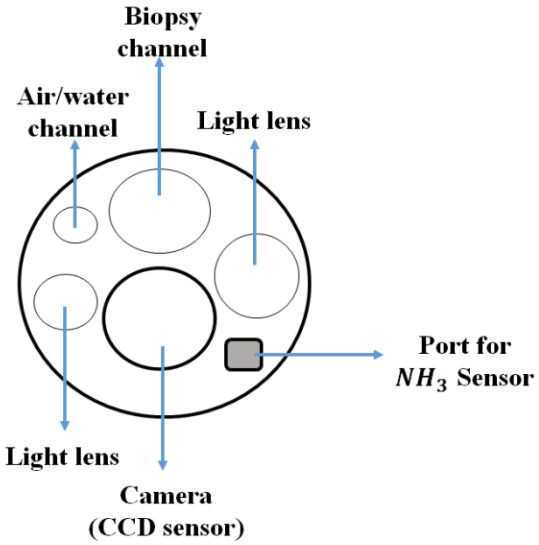

Figure 3. Conceptual diagram of a modified video endoscope distal tip for multi-mode sensor integration.

In the proposed design, the integration of the NH_3 sensor into the distal end of the endoscope, with minimal structural changes made to the structure of the biopsy channel light fibers and air/water channel, does not have any adverse effect on the optical, mechanical, and clinical functionality of the device. This ensures that the sensor can be used in real-time in a clinical environment and provides a methodological framework that can be used to evaluate quantitatively the results obtained from the sensor. Therefore, for the NH_3 concentration to be clinically meaningful, it is considered necessary to normalize the sensor outputs according to physiological ranges. According to clinical and experimental studies, ammonia concentrations in a healthy stomach environment are generally <10 ppm and range from 20-100 ppm during Helicobacter pylori infection [9]. Therefore, signals obtained from the NH_3 sensor were converted to ppm units and processed according to the normalization model presented below.

$$(NH_3)norm = \frac{NH_3 - C_{min}}{C_{max} - C_{min}} \quad (1)$$

Where,

NH_3 - measured ammonia concentration,

C_{max} and C_{min} - are the minimum and maximum physiological values based on medical literature.

Two different physiological concentration ranges were taken into account for normalising NH_3 concentration measurements. In the first scenario, a range of 10 to 100 ppm was chosen to represent a wide range of clinical concentration levels. In the second scenario, a range of 5 to 90 ppm was chosen to demonstrate the impact of low concentration changes.

In this study, it was accepted that the minimum and maximum physiological limits to be used in normalising the results of measurement from ammonia (NH_3) sensor would be 10 ppm and 100 ppm, respectively. These values were based on the results of clinical and experimental studies concerning basal levels of ammonia in a healthy stomach environment and high metabolic activity due to Helicobacter pylori infection [10, p. 205].

Table 1

Normalized NH_3 concentration and corresponding risk category based on reference range of 10 to 100 ppm.

NH_3 ppm	NH_3 norm	Risk Category
15	0.05	Low
20	0.11	Low
30	0.22	Suspicious
40	0.33	Suspicious
45	0.38	Suspicious
50	0.44	Suspicious
65	0.61	High
70	0.66	High
90	0.88	High

In an alternate normalisation scenario, this study set the minimum and maximum limits for ammonia concentration at 5 ppm and 90 ppm, respectively. This is with the aim of increasing sensitivity to small changes in ammonia levels and improving the assessment of early functional and metabolic changes in the gastric environment.

Table 2

Normalized NH_3 concentration and corresponding risk category based on reference range of 5 to 90 ppm.

NH3 ppm	NH3 norm	Risk Category
15	0.12	Low
20	0.18	Low
30	0.3	Suspicious
40	0.4	Suspicious
45	0.47	Suspicious
50	0.53	High
65	0.7	High
70	0.76	High
90	1	High

Figure 4 shows a comparison chart for the normalised indices calculated using two different physiological normalisation ranges ($C_{min} = 10$ $C_{max} = 100$ $C_{min} = 5$ $C_{max} = 90$) for the measurement of the ammonia (NH_3).

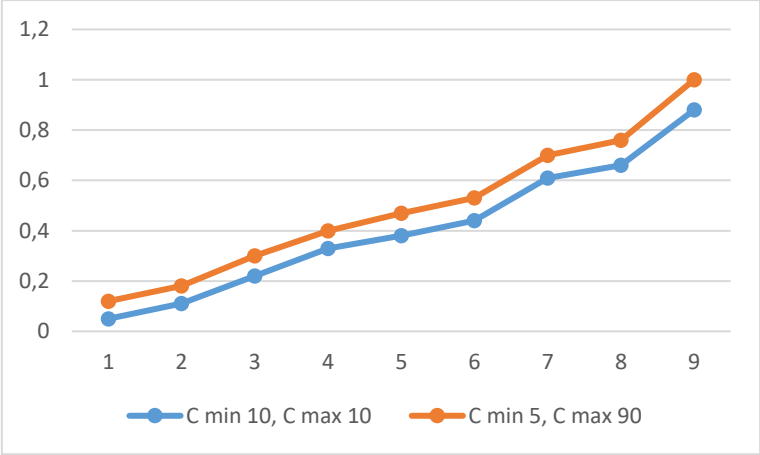

Figure 4. Comparative analysis of NH_3 measurements normalised at different minimum and maximum limits.

The ammonia concentration measured was normalized by a standard min-max scaling method to fall within the physiological range of [0,1] units, which is a common practice in biomedical signal processing and machine learning-based analysis.

Normalized NH_3 indicators are divided into clinical categories as follows:

- When the normalized ammonia level $(NH_3)norm < 0.2$, the probability of Helicobacter pylori infection is considered low.
- For, $0.2 \leq (NH_3)norm < 0.5$, the result is classified as suspicious, and additional confirmatory diagnostic procedures are recommended.
- When $(NH_3)norm \geq 0.5$, a high probability of H. pylori infection is assumed.

The above method of normalization makes it easy for the interpretation of raw values obtained from the NH_3 sensor and allows for the development of a single index that can be used for comparison in various patients and measurement conditions. In addition, the division of the normalized NH_3 index into clinical categories allows for additional information that can be used in the physician's process of making decisions in real time while carrying out an examination. The advantage of using this method is that it eliminates the possibility of missing out on H. pylori infection, especially in cases that are difficult to detect and where biopsy is not feasible.

Conclusion

The proposed methodological framework enables NH_3 measurements to be used not only as a quantitative indicator but also as a digital diagnostic indicator. The normalized sensor data is combined with multimodal endoscopic data such as standard white light images, NBI images, thermal images, or pH sensor data in the next step of the process, which can be used as suitable input data for complex analysis. This approach provides functional information input to the system to overcome the limitations of decision-making based solely on visual information in endoscopic diagnosis.

In the next phase of research, it is planned that these normalized NH_3 indicators will be integrated into artificial intelligence-based analysis. Specifically, machine learning and deep learning models that consider the temporal and spatial variation of sensor data will be applied to automatically detect H. pylori infection, assess the risk level, and recommend the most suitable areas for biopsy. This provides a scientific basis for developing smart diagnostic systems that can enhance the objectivity of endoscopic diagnosis and reduce random biopsies while allowing physician control.

References:

1. Muto M. et al. Narrow band imaging: a new diagnostic approach to visualize angiogenesis in superficial neoplasia //Clinical Gastroenterology and Hepatology. – 2005. – Т. 3. – №. 7. – С. S16-S20. https://doi.org/10.1016/S1542-3565(05)00262-4

2. Liu Z. et al. Diagnostic performance of white light endoscopy, narrow band imaging, and flexible spectral imaging color enhancement for early gastric cancer: a systematic review and meta-analysis //Quantitative Imaging in Medicine and Surgery. – 2025. – Т. 15. – №. 6. – С. 5534. https://doi.org/10.21037/qims-24-482

3. Zang H. et al. Metabolic alterations in patients with Helicobacter pylori-related gastritis: The H. pylori-gut microbiota-metabolism axis in progression of the chronic inflammation in the gastric mucosa //Helicobacter. – 2023. – Т. 28. – №. 4. – С. e12984. https://doi.org/10.1111/hel.12984

4. Gopakumar H. et al. Role of advanced gastrointestinal endoscopy in the comprehensive management of neuroendocrine neoplasms //Cancers. – 2023. – Т. 15. – №. 16. – С. 4175. https://doi.org/10.3390/cancers15164175

5. Li H. et al. Advanced endoscopic methods in gastrointestinal diseases: a systematic review //Quantitative Imaging in Medicine and Surgery. – 2019. – Т. 9. – №. 5. – С. 905. https://doi.org/10.21037/qims.2019.05.16

6. Ikenoyama Y. et al. Detecting early gastric cancer: Comparison between the diagnostic ability of convolutional neural networks and endoscopists //Digestive Endoscopy. – 2021. – Т. 33. – №. 1. – С. 141-150. https://doi.org/10.1111/den.13688

7. Bidani K. et al. Optical Imaging Technologies and Clinical Applications in Gastrointestinal Endoscopy //Diagnostics. – 2025. – Т. 15. – №. 20. – С. 2625. https://doi.org/10.3390/diagnostics15202625

8. Boese A. et al. Endoscopic imaging technology today //Diagnostics. – 2022. – Т. 12. – №. 5. – С. 1262. https://doi.org/10.3390/diagnostics12051262

9. Popa C., Petrus M., Bratu A. M. Ammonia measurement in human breath of subjects with Helicobacter pylori using photoacoustic spectroscopy //Journal of biophotonics. – 2024. – Т. 17. – №. 6. – С. e202400074. https://doi.org/10.1002/jbio.202400074

10. Lee O. J., Lee E. J., Kim H. J. Correlations among gastric juice pH and ammonia, Helicobacter pylori infection and gastric mucosal histology //The Korean journal of internal medicine. – 2004. – Т. 19. – №. 4. – С. 205. https://doi.org/10.3904/kjim.2004.19.4.205

11. Graham D. Y., Miftahussurur M. Helicobacter pylori urease for diagnosis of Helicobacter pylori infection: A mini review //Journal of advanced research. – 2018. – Т. 13. – С. 51-57. https://doi.org/10.1016/j.jare.2018.01.006