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Influences on the Sensitivity of Camera-Based Colorimetric Gas Sensors Systems

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Summary:
Colorimetric gas sensors detect analytes through a color-changing reaction of a sensor material. This work shows how light sources and image formats affect the sensitivity of camera-based colorimetric sensor. For this work, bromocresol green was embedded in polyvinyl chloride for NH_3 detection. Three white LEDs with different color temperatures were tested, revealing that the neutral white LED exhibited the highest sensitivity. Furthermore, RAW image data provided the best results due to its higher bit depth compared to JPG and PNG formats, significantly enhancing sensor system sensitivity.

Keywords: Colorimetric gas sensor, Raspberry Pi camera, light source, pH indicator, data format

Background, Motivation and Objective

Colorimetric gas sensors identify analyte gases by causing a visible color change in a gas-sensitive material, known as the sensor material. These sensors provide several benefits, such as cost efficiency and operation at room temperature. A colorimetric sensor consists of three key components: a sensor material, a light source, and a detector that measures the color change [1]. The impact of the sensor material on the sensitivity of the gas sensors, e.g. examining the effects of the sensor dye, the matrix material, and the plasticizer has been investigated by previous studies [2]. This work concentrates on the impact of the light source and the image data format on the results provided by the sensor system. Therefore, a well-known sensor dye bromocresol green in polyvinyl chloride (PVC) as the polymer matrix is used as sensor material for the detection of the gas NH_3. When exposed to NH_3, a pH reaction occurs resulting in a color change of the sensor dye from orange to blue. As a detector for the colorimetric gas sensor a Raspberry Pi Camera v1 is applied. The sensor material was directly applied on the camera pixels to produce the gas sensitive camera sensor. To investigate the impact of the light source three different types of white LEDs with different color temperatures were tested: a warm white (WW, 3000 K), a cold white (CW, 11 000 K) and a neutral white (NW, 5000 K) LED. The camera records images in 10 bit RAW format or processed as 8 bit images e.g., in a PNG or JPG format. In order to investigate the impact of the data format the sensitivity to NH_3 is compared for RAW, PNG and JPG images.

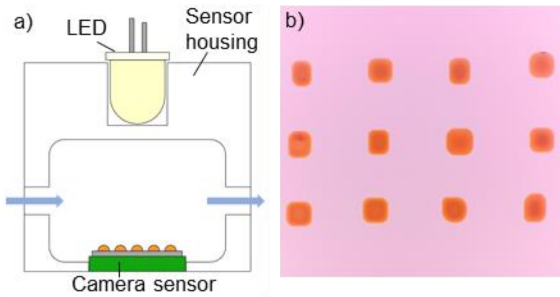

Fig. 1. Schematic drawing of the sensor set-up (a) and JPG image recorded by the camera sensor illuminated by NW LED (b).

Design of the colorimetric gas sensor

The setup of the test system includes a Raspberry Pi Camera v1 as the detector (Figure 1a). The housing and optics were removed and the blank camera sensor is directly functionalized with the sensor material using a 0.5 µl syringe. The sensor material consisted of BCG (70 mmol/l) and PVC (7.5 w%) diluted in benzoic acid methyl ester and ethanol (3/1). 0.05 µl of the sensor material solution was dispensed on the camera in a 4x3 grid with a spot size of 200–300 µm. The functionalized camera sensor was placed inside a white plastic housing. The camera sensor was illuminated by a white LED through the white plastic chamber and was placed on top of the camera sensor. The white LEDs have uniform light intensity and beam angle. The current was set to 3 mA with a fixed shutter time of the camera of 200 µs. The sensor response is the change of the red, green and blue (RGB) color values upon NH_3 exposure. Therefore, an image series was recorded in JPG, PNG and RAW data format (Figure 1b). The images are processed to extract the color values by superimposing a 4x3 grid on each image, and averaging the RGB values over a circular region with a diameter of 30 pixels at the center of each sensor spot.

Results

The reaction of the sensor material with NH_3 leads to changes in the color values R, G and B, and is exemplarily demonstrated for the R value (ΔR) in the following. ΔR Is calculated by the difference of R value before and during NH_3 exposure and is averaged over the sensor spots. The spectrum of the light source influences the sensitivity and reproducibility of the camera based colorimetric gas sensor as exemplified by the JPG images (Figure 2). The sensor material shows the highest sensitivity upon NH_3 illuminated by NW light, followed by CW light. The lowest sensitivity is obtained with the WW LED.

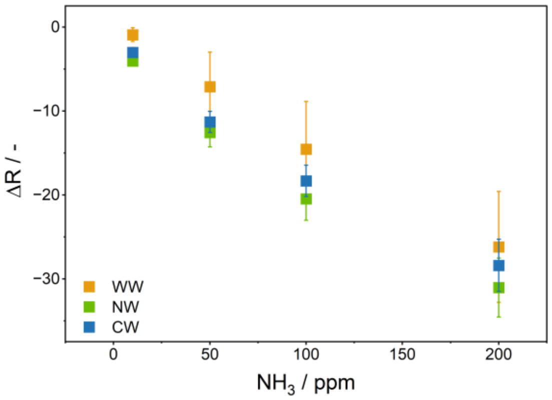

Fig. 2. Change in the R color value (ΔR) upon exposure to 10, 50, 100 and 200 ppm of NH_3 at 55% r.H., 25°C, and 1013 mbar using the WW, NW and CW LED.

The WW LED has the highest proportion of red light among the selected LEDs. This leads to an oversaturation of the R value, requiring higher concentrations of NH_3 to cause a visible color change. The standard deviation of ΔR is significantly higher than for NW and CW LED. The variation in the response of the sensor spots illuminated by the WW LED is significantly higher. This can be related to an inhomogeneous illumination of the camera sensor. Consequently, the WW LED is considered as unsuitable, whereas the NW LED is identified as the best light source for this set-up.

Furthermore, the data format of images does impact the sensor's sensitivity, shown for the NW LED as the light source (Figure 3). Using RAW images leads to higher sensitivity for the sensor system than JPG and PNG images. There is no significant difference in sensor response between PNG and JPG images.

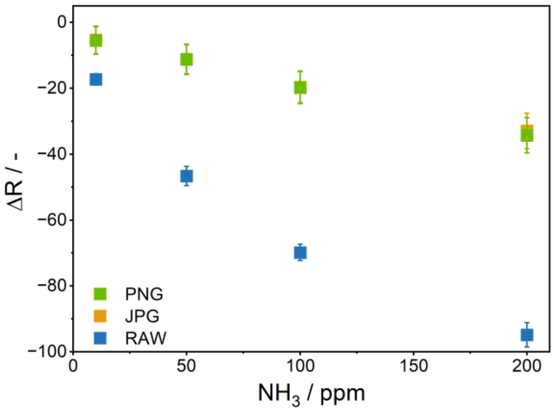

Fig. 3. Change in the R color value (ΔR) upon exposure to 10, 50, 100 and 200 ppm of NH_3 at 55% r.H., 25°C and 1013 mbar, comparing different data formats illuminated by the NW LED.

The significantly higher sensitivity of the RAW image is caused by its higher bit depth. 8 bit images can display a total number of 256 color values per color channel, while 10 bit images display 1024 color values. Thus, the higher color depth and finer gradation of colors with 10 bit compared to 8 bit images lead to higher sensitivity of the sensor.

Conclusion

The performance of camera-based colorimetric gas sensors can be significantly enhanced by selecting the appropriate light source and image data format. In this setup, the highest sensitivity was achieved using the neutral white NW LED, which resulted in improved sensitivity. Additionally, recording images in RAW data format further increased the sensitivity.

References

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