SWIR Imaging for Methanol Detection on Reflective Backgrounds

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Abstract: Methanol is a low-contrast, semitransparent liquid in the visible spectrum, making its detection challenging—especially when sprayed onto reflective surfaces such as metals commonly found in industrial settings. This study investigates the effectiveness of a VIS-SWIR camera system in enhancing the visibility of methanol sprays and droplets against a silver background, simulating metallic pipelines. The experiment involved image acquisition using both a standard visible (VIS) camera and a VIS-SWIR system, with and without a 1550 nm LED and spectral filter. These configurations were tested to assess the influence of shortwave infrared (SWIR) imaging and spectral filtering on contrast enhancement. Results show that methanol is barely distinguishable in the visible range due to its transparency and the reflectivity of the background. In contrast, the VIS-SWIR camera significantly improved droplet and spray visibility. These findings highlight the potential of SWIR imaging as a powerful tool for detecting low-contrast substances in environments with reflective surfaces.

Keywords: Methanol; SWIR imaging; Infrared imaging; Reflective surfaces.

Abbreviations: VOC, volatile organic compound. VIS, visible. SWIR, short-wave infrared. LED, Light Emitting Diode. LWIR, long-wave infrared. NIR, near infrared. VIS-SWIR, visible-short wave infrared. CMOS, Complementary Metal-Oxide-Semiconductor. CCD, Charge-Coupled Device. InGaAs, Indium Gallium Arsenide.

1.Introduction

Methanol is a highly flammable and volatile organic compound (VOC) extensively employed in industrial and laboratory applications, such as in fuels, solvents, and chemical synthesis processes [1]. Due to its high toxicity and low flash point, even small leaks, whether as vapor, droplets, or aerosolized sprays, pose significant safety hazards, including risks of fire, explosion, and harmful exposure to workers. Consequently, rapid and accurate detection of methanol leaks is critical, especially in high-risk environments like refueling stations or chemical processing facilities [2].

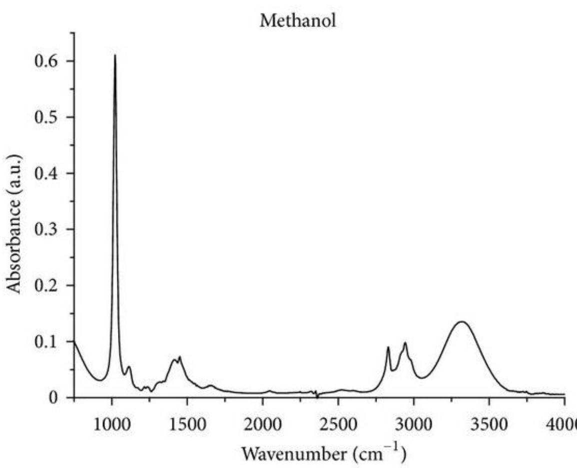
A range of detection strategies has been investigated for chemical leak detection,

For instance, Lee et al [3] developed a remote sensing system employing long-range infrared cameras to monitor chemical emissions in industrial complexes. Moreover, Naku et al. [4] proposes the identification of volatile organic liquids with fiber-optic sensors.

Additional approaches include the work of Zhao, Q et al [5], who proposed an image enhancement method for gas leak detection based on infrared imaging, aimed at improving visual clarity in noisy or cluttered environments. In the visible (VIS) spectrum, methanol is nearly transparent and exhibits minimal contrast against metallic backgrounds, rendering traditional optical inspection methods ineffective under such conditions. This limitation underscores the necessity of exploring alternative spectral regions that offer enhanced sensitivity and selectivity.

The shortwave infrared (SWIR) region (0.9–1.7 µm) presents significant advantages in this context, primarily due to its ability to reveal specific absorption features of chemical compounds that are undetectable in the VIS and near-infrared (NIR) regions. Methanol, in particular, displays strong absorption bands within the 1400–1500 nm range, as seen in Figure 1, making it highly amenable to SWIR-based detection strategies [4, 6]. These optical properties are common among monohydric alcohols, whose infrared absorption profiles have been systematically investigated and documented for their diagnostic relevance in spectroscopic applications [6].

Figure 1. Graph of infrared absorption spectrum of methanol, showing distinct bands in the SWIR region (1400–1500 nm).



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This study aims to propose a selective, practical and real-time system for detecting methanol leaks, such as droplets or sprays, on pipes in confined industrial environments by evaluating the feasibility of using VIS-SWIR imaging, in conjunction with spectral filtering, for visual identification of methanol on reflective metallic surfaces.

The use of a VIS-SWIR camera was motivated by its dual capability to operate both in the visible and SWIR ranges, enabling methanol detection within its characteristic in SWIR band while also allowing visualization of other features in the visible spectrum.

To achieve this, we performed imaging experiments using a setup configured for shortwave infrared (SWIR) detection. A long-pass filter with a cutoff at 750 nm was employed to capture methanol absorption at its characteristic band, while also enabling ambient visualization under SWIR illumination. A 1550 nm LED was used as an active light source, enhancing image contrast under filtered conditions. For baseline comparison, a conventional visible-light camera was utilized under identical illumination. Tests were carried out on both matte and reflective silver backgrounds, simulating typical industrial surfaces such as pipelines and storage tanks.

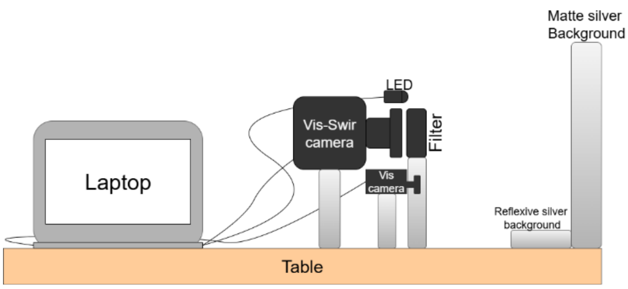
The main contribution of this work lies in enabling the selective detection of fine methanol droplets and sprays, addressing the challenge of differentiating transparent liquids, such as water and methanol, providing a faster, easier, and real-time approach in confined industrial environments. The proposed methodology holds broader potential for adaptation to other chemical substances with SWIR spectral features. This versatility opens possibilities for applications in industrial monitoring, process control, and environmental diagnostics.

2. Materials & Methods

The experimental setup utilized two distinct imaging systems to enable comprehensive spectral analysis. High-resolution visible images were acquired using a MU196CR-ON-TC camera (Edmund Optics #83-107 lens). For short-wave infrared (SWIR) characterization, an Atlas SWIR 1.3MP IP67 camera with an H0514-VSW lens and FELH0750 long-pass filter (>750 nm) was used to isolate methanol's spectral features.

As visualized in Figure 2, the dual-camera configuration enabled simultaneous capture of methanol's absorption characteristics across the visible and SWIR spectral ranges, facilitating direct comparison of methanol’s optical behavior in each domain.

Figure 2. Diagram of the bench-top experimental setup: VIS and VIS-SWIR cameras with lenses and filter, background surfaces, and a methanol sample.



To isolate methanol’s spectral signatures and optimize detection, a long-pass filter (750 nm cutoff) was paired with the VIS-SWIR camera. This configuration served two critical functions: (1) Spectral Isolation: by blocking visible light to focus on the SWIR range (where methanol absorbs strongly at 1550 nm), enhancing contrast for droplets and sprays. (2) Reflection Suppression: Mitigating overpowering specular reflections from metallic surfaces, which often obscure subtle features in the visible spectrum.

The visible channel of the VIS-SWIR camera was excluded due to its inferior performance compared to the dedicated VIS camera, which offered higher resolution and dynamic range in the 400–700 nm band. This is because InGaAs-based SWIR sensors have lower sensitivity and image quality in the visible range compared to dedicated VIS cameras like CMOS or CCD.This separation ensured reliable baseline data and avoided cross-spectral artifacts.

The experimental results validated that methanol’s dominant optical signature lies in the SWIR range, justifying the use of the long-pass filter. Illumination during all controlled tests was provided by a ThorLabs LED1550L, centered at 1550nm, selected to align with the methanol's absorption band and enhance its contrast in the filtered SWIR images. In other phases of the experiment, illumination conditions were without quantitative measurements of lux or reflectance due to the dynamic and open nature of the lightning setup(e.g. sunlight entering through windows). Rather than enforce artificial constraints, the decision was made to document and accept this variability to preserve the validity of the test scenario. The samples were contained in a cuvette filled with concentrated (pure) methanol, and the tests were performed using three different background surfaces: plain white paper(low reflectivity), a metallic silver surface(high specular reflectivity), and a matte silver surface(diffuse reflectivity).

The experimental procedure was structured into four main stages, Table 1 summarizes each stage with a brief description for quick reference.

Table 1. Summary of experimental procedures

Stage	Name	Description
Stage 1	Methanol in cuvettes	Assessment of methanol visibility under varying illumination conditions
Stage 2	Methanol Spray	Detection of aerosolised methanol sprayed on reflective surfaces under controlled LED illumination
Stage 3	Outdoor Dripping	Simulation of real-world inspection by dripping methanol onto surfaces under diffuse natural light.
Stage 4	Outdoor Spray	Visibility evaluation of spray deposited methanol under uncontrolled ambient light

In the initial phase, the optical contrast of methanol inside the cuvette was assessed against each background material under ambient laboratory lighting.

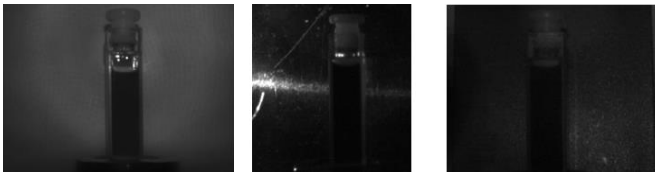
Images were captured under two conditions: with and without 1550 nm LED illumination, as shown in Figure 3 to Figure 5. This approach allowed a direct comparison of lighting scenarios and facilitated the evaluation of how this specific wavelength influences methanol visibility.

Figure 3. Visible camera and LED on. Matte silver background (left), reflective silver background (right)

A

B

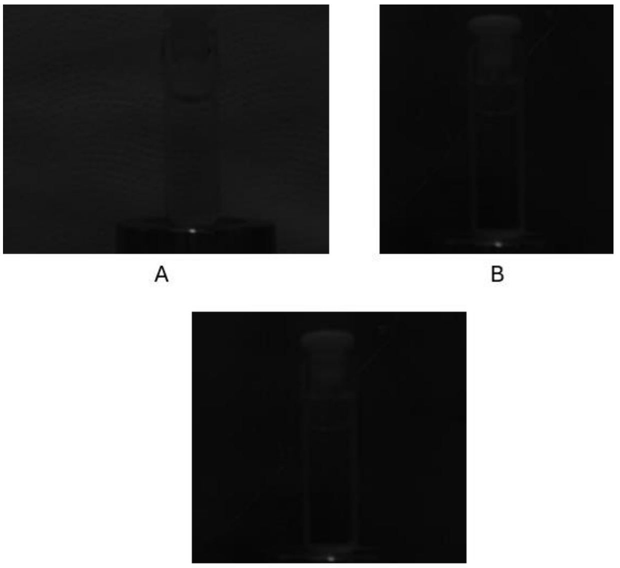
Figure 4. SWIR camera with LED on and ambient light. Paper background (left), reflective silver background (middle), matte silver background (right).



A B C

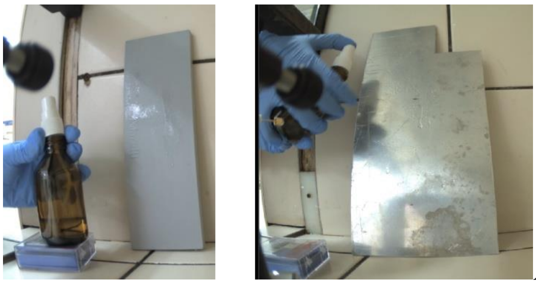
Figure 5. SWIR camera with LED off and ambient light. Paper background (left), reflective

silver background (middle), matte silver background (right).



In Stage 2, the experiment simulated a more dynamic condition: methanol was sprayed onto the metallic and matte silver surfaces to verify its detection in less concentrated forms. The Vis-SWIR camera operated with the FELH0750 filter and the 1550 nm LED source, while the visible camera used only the LED as its light source. In both configurations, ambient laboratory lighting remained active throughout image acquisition. This arrangement enabled a comparative analysis of the two imaging systems' capabilities in detecting trace amounts of methanol dispersed as a fine aerosol. Representative image captures from this stage are presented in Figure 6 and Figure 7.

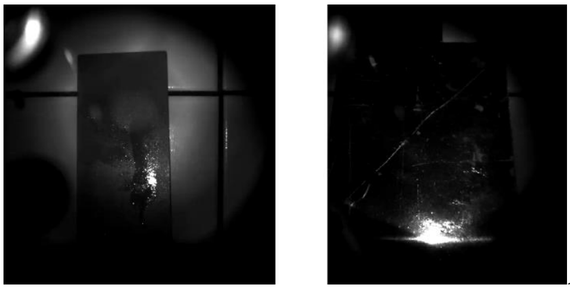
Figure 6. Spray against surfaces using a visible camera with LED on. Matte silver background (left), reflective silver background (right).



A

B

Figure 7. Spray against surfaces using SWIR camera with LED on and 750nm filter. Matte silver background (left), reflective silver background (right).



A

B

Stage 3 was planned to simulate a rapid response scenario in which an operator might need to perform a visual inspection of a specific segment of an industrial installation under non-standardized lighting conditions.Methanol was applied via dripping onto both reflective and matte silver surfaces. Ambient illumination was provided exclusively by diffuse sunlight, introduced by opening laboratory windows which are coated with UV-protective film. No control over the lighting was performed, as the intention was recreate the variability encountered in real-world iindustrial environments, ranging from outdoor settings to confined areas with minimal or indirect natural light, llike the one shown in

Figure **8**, with results shown in Figure 9 and Figure 10. The camera configurations remained consistent with the previous stage to ensure methodological consistency. This phase aimed to assess detection performance under natural lighting, as would be expected in field deployments.

Figure 8. Example of a confined industrial environment

Figure 9. Droplets against a matte and reflective silver background, captured with visible camera and LED on.

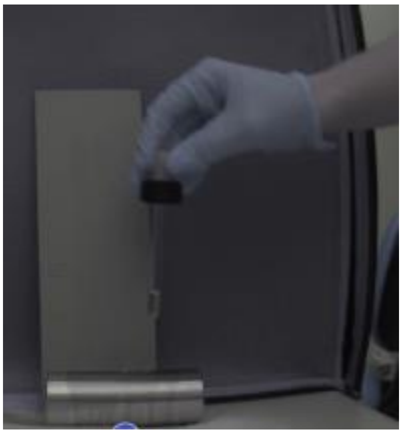
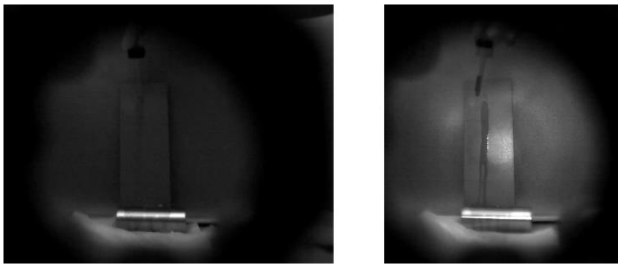


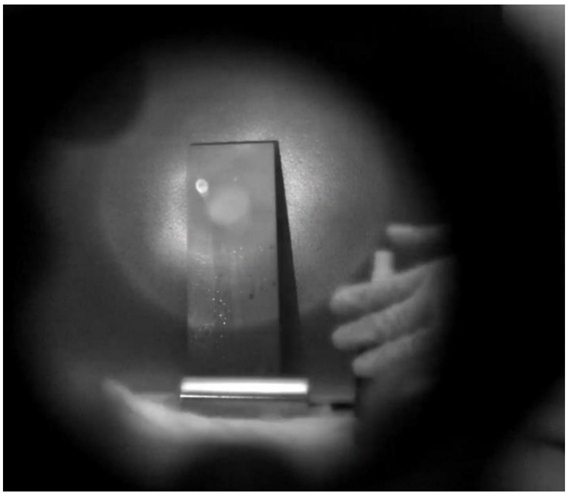
Figure 10. Droplets against a matte and reflective silver background, captured with SWIR camera and ambient light. With LED off (left), with LED on (right).



A B

In the final stage (Stage 4), the same outdoor scenario and camera configurations were maintained, as in stage 3 however, instead of dripping, methanol was applied by spraying, producing a dispersed aerosol pattern across the test surfaces, as depicted in Figure 11. This approach was employed to evaluate how variations in the method of methanol deposition, droplet vs spray, affectsvisibility and contrast in the captured images.

Figure 11. Spray against a matte silver background, captured with a SWIR spectrum camera, 1550nm LED illumination and a 750nm longpass filter with ambient light.



3. Results and discussion

Figure **7**A and Figure 10B illustrate the most significant outcomes achieved shortwave infrared (SWIR) imaging system configured with an LED source centered at 1550 nm and a long-pass optical filter with a cut-on wavelength of 750 nm. Figure **7**A, methanol was applied via aerosol spraying onto a matte silver substrate, while Figure **10**B shows the same background with methanol deposited in droplet form. In both images, methanol exhibited absorption at 1550 nm, appearing as a region of attenuated intensity than the background. Longpass filter improves spectral contrast by eliminating background interference from visible wavelengths, thereby enhancing the selectivity and reliability of the detection system. Under the same conditions, the visible camera could not produce sufficient contrast to discriminate methanol from the background, demonstrating the inadequacy of visible-only imaging for near-infrared chemical sensing tasks.

In the image presented in Figure 10B, ambient light combined with 1550nm LED illumination contributed to the overall visibility of the scene, aiding visual interpretation without compromising spectral detection. Furthermore, the matte silver substrate improved contrast and enhanced discernibility of methanol, due to its reduced specular reflectance.

A comparative analysis between the two deposition methods revealed considerable morphological differences. The spray produced a wider absorption zone. In contrast, the droplets application resulted in sharper absorption boundaries with more localized features, offering advantages for tasks involving morphological investigations.

These observations validate the effectiveness of SWIR imaging configuration, comprising a broadband sensitive camera, narrowband LED illuminations, and long-pass optical filtering for remote, non-invasive methanol detection.

A dedicated SWIR-only camera, without VIS sensitivity, could deliver equivalent performance with improved cost-effectiveness and easier availability in the market. This finding suggests that future implementations could benefit from simplified setups using purely SWIR imaging hardware, especially in practical industrial scenarios.

4. Conclusion

The combined use of visible and SWIR cameras proved to be an effective approach for selective methanol detection, with the SWIR system demonstrating a distinct advantage in highlighting the contrast between methanol and different background surfaces. The captured images confirmed the method’s effectiveness, particularly in the spectral range near 1550 nm, where methanol exhibits stronger absorption.

The data collected throughout the experiments were essential for understanding the optical behavior of methanol in the near-infrared range, validating the sensitivity of the SWIR camera to the presence of the compound. These controlled experiments confirmed the effectiveness of leveraging SWIR absorption characteristics to identify methanol leaks under realistic conditions, such as those found in industrial environments, addressing a critical need for enhanced safety and monitoring technologies in high-risk industrial environments.

Furthermore, this analysis deepened our understanding of how illumination, spectral filtering, and surface properties interact to influence detection performance. The methodology employed in this study offers foundation for future applications in spectral detection scenarios, particularly in contexts requiring remote and non-invasive identification of hazardous liquids or trace chemical residues. Future work could include tests to assess repeatability, reliability, and the detection of different volumes of methanol, further validating and extending the practical applicability of the approach.

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