

Limitations of LWIR Cameras for Industrial Air Leak Detection

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Summary: Infrared (IR) cameras have seen increasing applications such as autonomous driving, healthcare, surveillance, condition monitoring within the industry, and many more. This work explores the possibility of using an unfiltered, uncooled VOx long-wave infrared (LWIR) detector to detect compressed air leaks. By loosening a fitting and comparing the minimum temperature within the area of the leak from a series of thermal images to the theoretical temperature drop expected from the expanded gas, we demonstrate limitations that these types of cameras are not generally suitable by themselves for detecting compressed air leaks within the industrial landscape.

Keywords: VOx, long-wave infrared, gas sensors, leak detection, compressed air

Introduction

Whether it is health hazards due to harmful substances, risk of explosion, machine failure, greenhouse gases, or increased energy consumption, detecting gas leaks has been a crucial process within the industry since the first industrial revolution. Starting with a steel wheel and a flint to create sparks to detect a firedamp, to the development of safety lamps [1], detecting gas leaks has since moved from contact-based methods, such as spray-on solutions, fixed sensor installations of ultrasonic transducers, accelerometers [3], or pressure transducers [4], to remote sensing solutions, such as vision-based approaches found in OGI cameras that make use of different IR regions to detect common industrial gases [2]. With OGI cameras that use varying detectors to cover different regions in the infrared spectrum, they are all fixed in what gases they can detect, and as seen in [2], none of them can detect compressed air. This raises the question whether LWIR cameras can also be used to detect compressed air leaks.

Methodology

First, a baseline for the expected temperature difference due to the expanding air needs to be established for comparison with the LWIR camera.

Knowing that Joule-Thomson expansion is an isenthalpic process, the expected temperature drop at room temperature (22 °C) can be calculated with Eq. 1 for air compressed to relative pressures in the range of 1 to 8 bar, which should cover most industrial systems.

$$\Delta T = \mu_{JT} \cdot \Delta P \quad \text{with} \quad \mu_{JT} = 0.3^\circ\text{C}/\text{atm} \quad (1)$$

For this, a Joule-Thomson coefficient of 0.3 °C/atm from [5] for air at 20 °C is used and should be sufficiently close to the ambient temperature of 22 °C.

Experimentally, a copper pipe was pressurized with air at a series of relative pressures between 1-8 bar and then released into the atmosphere through an artificial leak created from loosening the threaded connection between a tee-fitting and a coupling, connected to a globe valve.

A Hikvision DS-2TD2637T-10/P was used to record images from the LWIR and visible (VIS) spectrum [6]. Since the camera lacks the ability to manually set temperature limits, a black body of type HT40B [7] set to 22 °C was used. Then, for each pressure level, 60 raw thermal and VIS frames were collected at approximately 1 s intervals when the artificial leak was supplied with air from the position seen in Fig. 1.

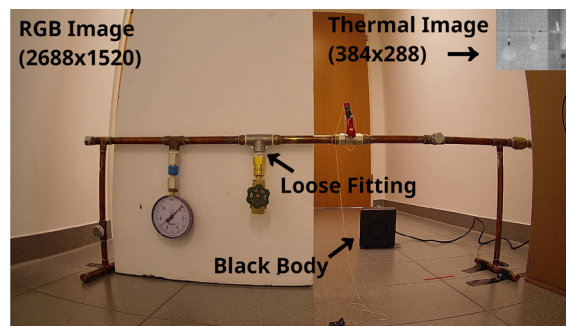


Fig. 1: Unprocessed images for LWIR and VIS

After calibrating the camera and performing stereo rectification (Fig. 2), a mask was created for the tee fitting (Fig. 3) where the artificial leak is located in the VIS image using the Meta Segment Anything 2 Model (SAM 2) [8]. This mask was then applied to the thermal image after performing non-local means denoising and temperature correction to find the pixel with the minimum measured temperature as seen in Fig. 4.

Without manual non-uniformity correction (NUC) available, the median of all pixel intensities within the black body reference circle (Fig. 4) was computed and the difference from the set temperature of 22 °C was subtracted from each pixel of the thermal image to correct measurements.

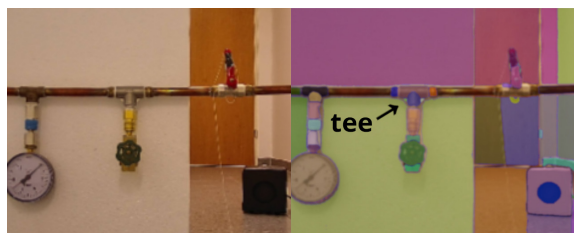


Fig. 2: VIS rectified

Fig. 3: VIS segmented

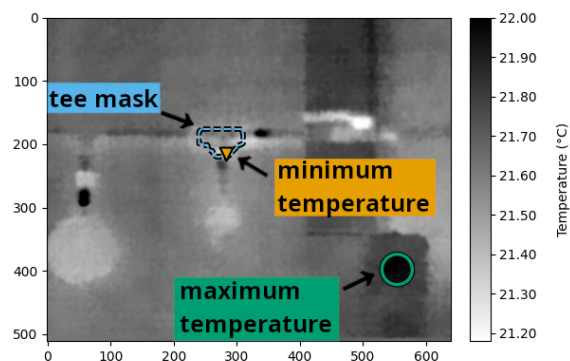


Fig. 4: LWIR rectified with temperature ROIs

Results

The distribution of the corrected minimum temperature differences measured at different compression levels compared to the theoretical temperature drop is shown in Fig. 5.

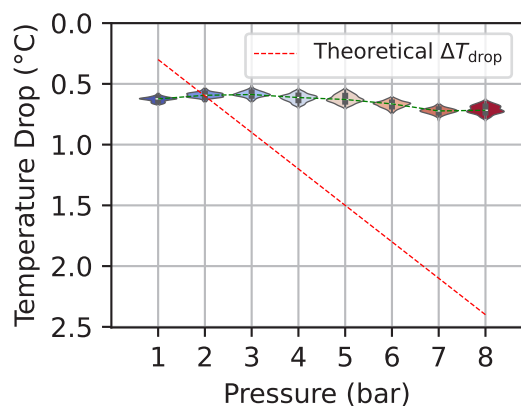


Fig. 5: Temperature drop for compressed air at 22 °C

Compared to the expected linear temperature drop, the measured temperature differences remain almost constant. Although the color bar as seen in Fig. 4 suggests that the theoretical temperature differences should be detectable, the thermal conductivity of the copper pipe seems to prohibit such a small local temperature difference to persist long enough.

Conclusion

In this work, a LWIR camera was used to explore whether a leak of compressed air could be detected in an industrial setting. The results show that even with the use of a black body reference, a LWIR camera experiences limitations to detect compressed air leaks at the tested location, leaving room for future exploration of different pipe materials or as a supporting modality for other sensors.

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