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Airflow Visualization Technique Using Infrared Camera

1. Introduction

Visualization of the flow of air, which is invisible to the eye, is effective for heat management in various environments, such as measures for protection against summer heat by controlling air-conditioners, management of product cooling processes and effective utilization of the waste heat of heat treatment furnaces. Existing visualization technologies include the tuft method[1)], PIV (particle image velocimetry)[2)], etc. When using the tuft method, it is necessary to arrange a large number of fluffy threads (tufts) that float in response to air currents, and for the PIV method, the construction of a test environment using tracer particles and a laser and other equipment is indispensable. Therefore, these methods cannot be applied in spaces with wide areas, such as large factories and server rooms, or in areas where tracer particles such as smoke cannot be used, such as semiconductor fabs and food plants, where contamination cannot be allowed.

To overcome these problems, JFE Techno-Research Corporation (JFE-TEC) developed an airflow visualization technique using an infrared camera, in which the temperature of the CO_2 contained in small amounts (up to a few 100 ppm) in the atmosphere is measured and used as a tracer. Because the visualization system has high portability, it is possible to measure objects that could not be measured with the existing technologies[3–5)]. This article introduces the principle of the airflow visualization technique using an infrared camera, together with several examples of application.

2. Principle of Airflow Visualization Using Infrared Camera

The purpose of general infrared cameras is to measure the surface temperature of solid objects. For this reason, general devices are designed in a wavelength band called an "atmospheric window" where infrared absorption by the atmosphere is minimal, but for this reason, airflows cannot be visualized simply by capturing thermal images. However, since absorption of infrared radiation by CO_2 in the atmosphere occurs in the wavelength region of approximately 4.3 μm[5)], JFE-TEC achieved airflow visualization by absorption by CO_2 using an infrared camera with sensitivity for the midwave infrared (MWIR) band of 3–5 μm.

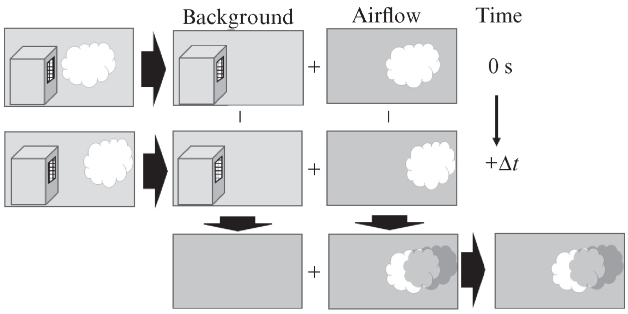

Fig. 1 Schematic diagram of principles in airflow visualization technique

Figure 1 shows an overview of the principle of airflow visualization. The thermal images captured by an infrared camera are the sum of the temperatures of the background and gas. However, if the background and gas are considered separately, the temperature of the solid surface, that is, the background temperature, appears substantially unchanged over a short time duration (Δt) of several seconds. On the other hand, unlike the background temperature, there are variations in the temperature of the gas, and when this gas moves, it can be observed as the "temperature change" during the time Δt. In other words, even though the temperature is the sum of the background temperature and gas temperature, if the temperature change during the short time of Δt is analyzed, the temperature change of the gas can be extracted in isolation, and the airflow can be recognized by converting this temperature change to a continuous time-series of video images.

Noise can also be reduced, allowing easier understanding of the movement of the airflow, by a temperature change analysis using the "short-time lock-in analysis method,"[3)] which is a proprietary image analysis technique developed by JFE-TEC. In the short-time lock-in method, time-series temperature data captured over a certain time are extracted with a short time window of a few seconds, and the lock-in analysis is performed while shifting the data in the time direction. In general lock-in analysis, synchronous detection is performed by treating the periodic signals of thermal loading as reference signals. However, in the short-time lock-in method, synchronous detection is performed

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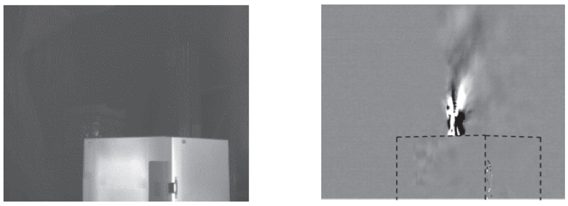
based on a virtual reference signal with a fixed frequency. Here, the conditions that enable airflow visualization by this technique are as follows.

① Temperature variations must exist in the airflow.
② An infrared camera with MWIR sensitivity is used.
③ No temperature fluctuations or movement occur in the background (fixed camera photography).



(a) Thermal imaging (b) Airflow visualization

Fig. 3 Airflow from heat treatment furnace[3)]

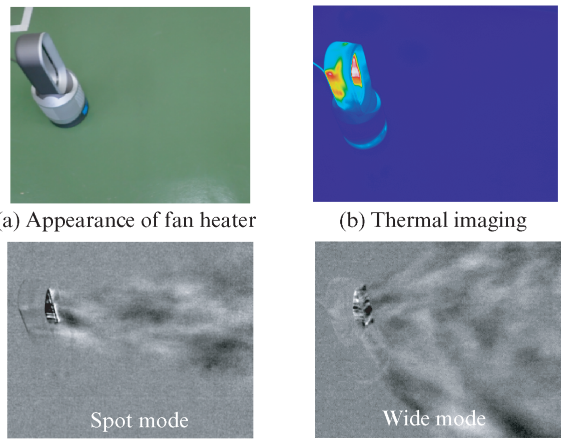
3. Examples of Airflow Visualization

Photo 1 shows the airflow visualization system used in measurement of the examples presented below. The system comprises an infrared camera, a notebook personal computer and a tripod. The detection element is InSb, which is sensitive to MWIR, the number of detection pixel is 640 x 512 and the maximum framerate is 125 fps.

3.1 Fan Heater

Figure 2 shows an example of an airflow visualization analysis of the warm air from a fan heater. Fig. 2 (a) shows the appearance of the object of measurement, Fig. 2 (b) is a thermal image captured by the infrared camera, and Fig. 2 (c) and (d) are the airflow visualization results. Greatly different warm air spread patterns were observed in the spot mode and the wide mode.

Photo 1 Airflow visualization system using infrared camera[3)]



(a) Appearance of fan heater (b) Thermal imaging

(c) Airflow visualization 1 (d) Airflow visualization 2

Fig. 2 Airflow with fan heater

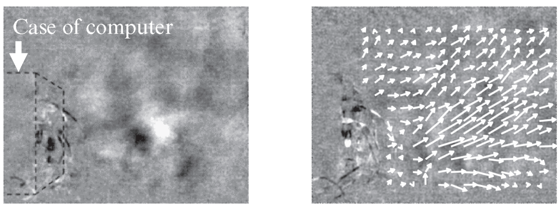
3.2 Heat Treatment Furnace[3)]

Figure 3 shows an example of visualization of the airflow leaked from a heat treatment furnace held at a temperature of approximately 800°C when the door was opened a few mm. The results of thermal imaging and airflow visualization are shown in Fig. 3 (a) and Fig. 3 (b), respectively. When the door is open, hot air from the exhaust gas hole at the top of the furnace leaks over a wide area.

3.3 Waste Heat from Computer and Vector Analysis

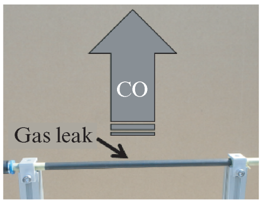
Figure 4 shows an example of airflow visualization of the waste heat discharged from a computer. Fig. 4 (a) is the result of airflow visualization, and Fig. 4 (b) shows the results of a vector analysis [3–5)] using PIV method analytical software in a video of the airflow visualization. A condition in which heat spreads outside the computer housing can be seen.

In recent years, computational fluid dynamics (CFD) has been used to create air flows to optimize the cooling systems of server rooms and to prevent entry of foreign matter from outside in order to maintain the cleanliness of food product plants, semiconductor labs and other facilities. By using the technology introduced here, it is possible to understand the characteristics of the airflow direction, which is expected to contribute to verification and improvement of the accuracy of CFD analyses.

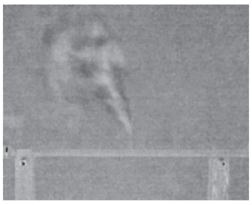


(a) Airflow visualization (b) Result of vector analysis

Fig. 4 Airflow of exhaust heat form computer



(a) Appearance of tube with leak



(b) Airflow visualization

Fig. 5 Airflow of CO gas leak

3.4 Gas Leak Detection by Airflow Visualization[5)]

Figure 5 shows an example of visualization of a leak (hole) in a tube connected to a gas cylinder and the gas leaking from the hole. Fig. 5 (a) shows the appearance of the object of measurement, and Fig. 5 (b) shows an example of detection by visualization of a CO leak. In addition to CO_2 and CO, it is also possible to detect other gases that absorb infrared radiation in the MWIR band, such as steam, propane, methane, etc.

4. Conclusion

The airflow visualization technique using an infrared camera introduced here enables direct visualization of the airflow without using smoke or other special tracers. The system has a simple configuration, comprising only the infrared camera and a personal computer. Because battery drive is possible, it has high portability and can be carried to various locations.

This visualization system has an extremely wide range of applications, as it can also be applied to optimization of the airflow in AI server rooms and air-conditioning systems of large office buildings, detection of gas leaks from various types of furnaces and other equipment, analysis of waste heat recovery processes and monitoring of cooling processes. JFE Techno-Research Corporation develops and sells this system, and also performs commissioned measurements utilizing this technology. In the future, we plan to develop this technology to new fields of application in order to respond to the new needs of customers.

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