Development of technology for enhancing the clarity of moving objects in thermal imaging cameras

Masanobu Masuda, Susumu Nishisaka

Key words

Thermography, infrared camera, capture of moving objects, image blur

We have developed the infrared thermography system model K2T, which suppresses image blur during the capture of moving objects, enabling the acquisition of clearer thermal images of such objects. The K2T system consists of an infrared camera (model K2TS) and an image processing controller (model K2TC). This system allows for effective inline inspections using thermal images on manufacturing lines where it was previously not feasible, thereby contributing to improved inspection quality and productivity.

1. Introduction

Recently, thermal images have been increasingly used in a variety of fields thanks to the improved performance and lower price of infrared cameras. It is also true that we have seen more thermal images on the street in the wake of the COVID-19 pandemic. Their scope of application is also expanding in industry. Efforts to replace conventional radiation thermometers used in inspections with infrared cameras are also increasing, as there are cases where thermal images are used for applications that are difficult to inspect with visible light cameras.

The newly developed infrared thermography system model K2T consists of the model K2TS infrared camera and the model K2TC image processing controller. The model K2TC image processing controller processes thermal images acquired by the model K2TS infrared camera to assess quality based on the surface temperature of objects.

Generally speaking, infrared detectors used in infrared cameras are roughly divided into quantum types and thermal types. Quantum infrared detectors offer superior performance in terms of responsiveness and sensitivity. However, they are not widely used due to their poor operability and price as they require a cooling structure. On the other hand, thermal infrared detectors do not require a cooling structure and are more affordable than the quantum type. However, they cannot track quick changes in infrared energy due to lower responsiveness and sensitivity.

The model K2TS employs a microbolometer infrared detector whose sensitivity is in the far-infrared region (wavelength domain of 8–14 μm). This thermal detector is relatively affordable but offers lower performance in terms of responsiveness and sensitivity, as described above. Therefore, it was difficult to acquire the shape and temperature of objects when capturing fast-moving objects due to the image blur issue described in section 3 of this article.

This article reports on this issue, the thermal image clarity enhancement technology that solves it, and the benefits of the technology.

Fig. 1. Camera and controller of the model K2T

2. Operation principle of infrared cameras

As described in section 1, the model K2TS infrared camera employs a microbolometer infrared detector. Microbolometers are fabricated by forming heat-sensitive elements in a 2D grid pattern on a silicon substrate with MEMS (micro electro mechanical systems) technology. This technology enables the formation of mechanical structures and electronic circuits on a single base material using semiconductor manufacturing processes. Figure 2 shows the heat-sensitive element structure in a microbolometer.

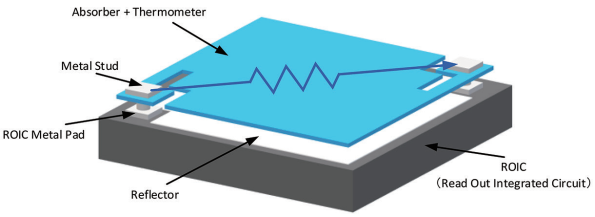

Fig. 2. Heat-sensitive element structure in a microbolometer

In the heat-sensitive elements of a microbolometer, the temperature of the thin film changes in response to infrared energy from the target object, and the resistance value of the thin film changes accordingly. At this time, a constant voltage is applied between the electrodes in figure 2 to read out the change in resistance value as a change in current. This change in current can be used to electrically read out the infrared energy.

The resistance changes of heat-sensitive elements arranged in a 2D grid pattern vary significantly from element to element. As a result, if the readout current changes are directly imaged, these variations in the properties of the heat-sensitive elements dominate the image, making it difficult to determine the shape of the target object. Therefore, they are calibrated using a planar blackbody furnace with known temperatures to standardize the properties. As a result, the infrared energy from the target object is output as data that can be converted into temperature values (thermal image).

3. Issues in measuring moving objects

Figure 3 shows a thermal image of a hot, stationary object. When an infrared camera using a typical microbolometer captures the movement of this hot object from left to right, the image blur shown in figure 4 occurs.

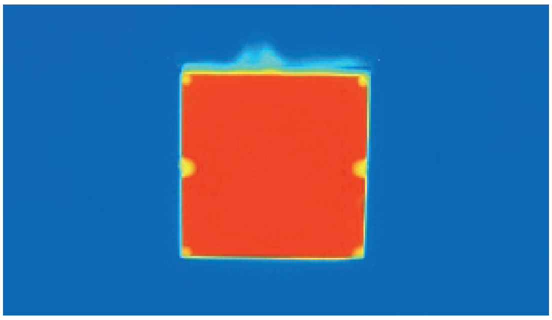

Fig. 3. Image of stationary object

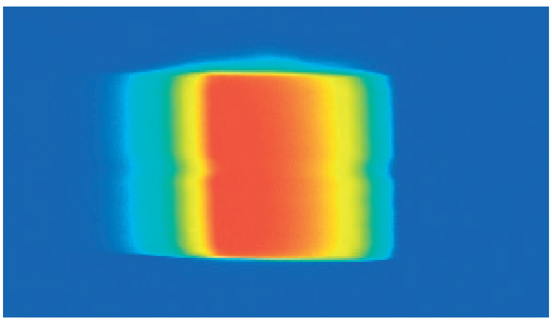

Fig. 4. Image with image blur

If image blur occurs, not only can the object shape not be determined accurately, but the detected temperature cannot be measured accurately either. For example, during the application inspection of hot-melt adhesive, used to seal cardboard or other materials, you can determine whether the hot-melt adhesive is present, but cannot measure the applied amount (area), the shape of the application, or the temperature after application. In other words, the application state cannot be effectively inspected.

Now let's delve into what image blur is. Blur may occur when capturing moving objects with a visible light camera as well as with an infrared camera. A common way of reducing it is to shorten the external energy capture time. This means reducing the exposure time in visible light cameras and the integration time in infrared cameras.

However, in typical infrared cameras, the integration time is fixed to the interval between consecutively captured images and cannot be freely selected.

Regarding these consecutively captured images as a video sequence, each image and the time at which it was captured are called a frame, and the next image and the time at which it was captured are called the next frame. The number of images captured per second is called the frame rate, which is expressed in frames per second.

Returning to the topic of integration time, in typical infrared cameras, the interval between one frame and the next frame corresponds to the integration time. Therefore, it is clear that image blur can be reduced by shortening the integration time, that is, by capturing images at a high frame rate.

With an integration time of approximately 1 μsec, this is where an infrared camera with a quantum infrared detector exhibits excellent responsiveness. Therefore, it can be said that the maximum frame rate depends on the performance of the readout circuit rather than that of the infrared detector.

In contrast, the heat-sensitive elements in a microbolometer, which is a type of thermal infrared detector, have a thermal time constant (τ) of approximately a dozen milliseconds. This means that even if a moving target is captured at a high frame rate, the response of the heat-sensitive elements is too slow. As a result, the transient state of the target object is captured, preventing accurate temperature measurement.

To overcome this issue, the newly developed model K2TS infrared camera incorporates the clarity enhancement processing described below. This enables even an infrared camera using a microbolometer to capture clear thermal images while suppressing image blur.

4. Image clarity enhancement processing

This section describes how to address the slow response of the heat-sensitive elements in the microbolometer to enhance image clarity. The responsiveness of a heat-sensitive element is generally represented by the following expression describing temporal changes in detected temperature.

$$T(t) = (T_0 - T_1)\exp\left(-\frac{t}{\tau}\right) + T_1 \qquad \text{Expression (1)}$$

Here, $T(t)$ is the temperature detected at time t; T_0 is the initial temperature (the temperature detected when $t = 0$); T_1 is the final temperature (the temperature detected when $t = \infty$); and τ is the thermal time constant of the heat-sensitive element.

Figure 5 shows the temporal change in the detected temperature, with the value detected at elapsed time $t + \Delta t$, $T(t + \Delta t)$, added.

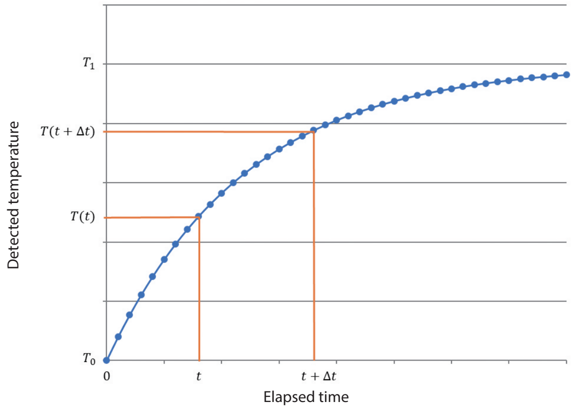

Fig. 5. Temporal change in the detected temperature

Here, the following relationship holds when T_1 is constant.

$$T(t+\Delta t) = (T_0 - T_1)\exp\left(-\frac{t+\Delta t}{\tau}\right) + T_1$$

$$= (T(t) - T_1)\exp\left(-\frac{\Delta t}{\tau}\right) + T_1 \quad \text{Expression (2)}$$

This is equal to the temperature detected at elapsed time Δt when $T(t)$ is the initial temperature and T_1 is the final temperature. Now, apply this expression to an infrared camera that captures images at a frame interval, t_f. When the temperature detected in the previous frame, T_{n-1}, is the initial temperature and the final temperature is T_t for the temperature detected in the current frame, T_n, the following expression holds, provided that the final temperature, T_n, remains unchanged between frames.

$$T_n = (T_{n-1} - T_t)\exp\left(-\frac{t_f}{\tau}\right) + T_t \quad \text{Expression (3)}$$

At this time, the final temperature, T_t, is expressed as follows based on the value in the current frame, T_n, and the value in the previous frame, T_{n-1}.

$$T_t = \frac{T_n - T_{n-1}\exp\left(-\frac{t_f}{\tau}\right)}{1 - \exp\left(-\frac{t_f}{\tau}\right)}$$

$$= kT_n + (1-k)\,T_{n-1} \quad \text{Expression (4)}$$

$$k = \frac{1}{1 - \exp\left(-\frac{t_f}{\tau}\right)}$$

In practical implementation, the frame interval, t_f, and the thermal time constant of the heat-sensitive element, τ, are known. Therefore, the final temperature can be estimated from the thermal images of two frames using expression (4).

5. Benefits of clarity enhancement

The newly developed model K2TS infrared camera can capture VGA-size (640 × 480 pixels) images at 60 frames per second. In addition, the frame rate can be increased by limiting the number of pixels read out (i.e., by reducing the image size). For example, the camera can capture QVGA-size (320 × 240 pixels) images at 240 frames per second. The result of capturing a moving object in QVGA-size images at 240 frames per second is shown below.

The result of capturing the previously shown moving object (used as an example of image blur in figure 4) with image clarity enhancement processing is shown in figure 6.

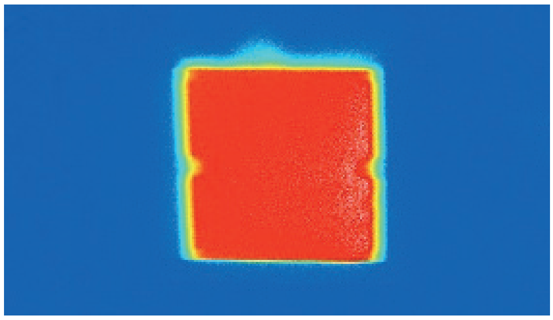

Fig. 6. Image of object in motion (with clarity enhancement)

Image blur is clearly suppressed compared to figure 4, and the obtained thermal image closely resembles the stationary state shown in figure 3.

Figure 7 shows information on the center line horizontally extracted from the thermal images in figures 3, 4, and 6.

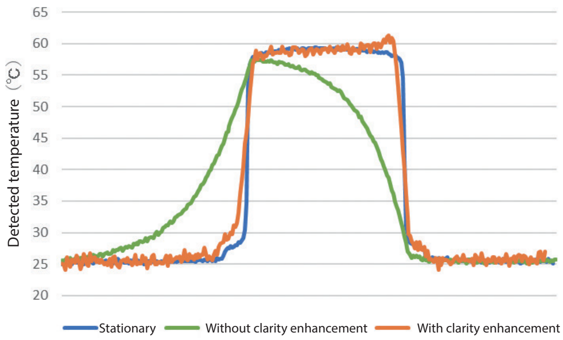

Fig. 7. Benefits of clarity enhancement for improving detected temperature

It shows that the detected temperature value is also closer to that in the stationary state with clarity enhancement than without it.

The result of the area measurement using these images is shown in table 1. Here, area measurement is one of the inspection functions provided by the model K2TC image processing controller. This function counts pixels that meet a threshold condition, such as being equal to or above a specific temperature (or equal to or below it, or within a specific range) and determines pass/fail based on the number of such pixels.

Table 1. Differences in detected area (number of pixels) depending on whether clarity enhancement is used

Temperature range	Stationary	Without moving object clarity enhancement	With moving object clarity enhancement
55 °C and above	9421	4374	9011
50 °C and above	9842	7328	9515
45 °C and above	10066	9423	9971
40 °C and above	10287	11248	10485
35 °C and above	10659	13392	11143
30 °C and above	11787	16944	12692

This table also shows that the result with clarity enhancement is closer to that in the stationary state than the result without it. Without clarity enhancement, although the results for areas at 45 °C and above and 40 °C and above are close to those in the stationary state, the results in other temperature ranges differ significantly.

Lastly, figure 8 shows the verification results of the benefits of the clarity enhancement processing when the speed of the moving object changes during area measurement with a threshold condition of 45 °C and above.

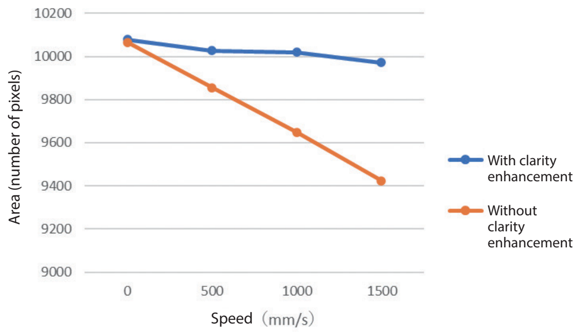

Fig. 8. Changes in the detection area due to the speed

Again, without being affected by the speed, the results with clarity enhancement are closer to those in the stationary state than the results without it.

What benefits would these results bring to practical applications? For example, when the amount of hot-melt adhesive applied is inspected on a manufacturing line, the application area can be checked by measuring the area in thermal images that falls within the predetermined temperature range. However, it is difficult to configure settings for images without clarity enhancement, as the area changes depending on the selected detection temperature range. In addition, the object must always move at a constant speed because the result differs depending on the speed. The line must also move at a constant speed when determining the threshold value for the amount applied. In contrast, with clarity enhancement, the temperature range can easily be set and stable results are obtained even if the line speed varies. Furthermore, the threshold value for the amount applied can be determined while capturing images with the line stopped since the result close to that in the stationary state is obtained.

As described above, inspection settings are easy, and higher inspection accuracy can be expected in the results of inspections like the one to inspect the amount of hot-melt adhesive applied.

6. Conclusion

This article mainly describes image clarity enhancement processing to suppress image blur in infrared cameras using a microbolometer, a type of thermal infrared detector. The model K2T thermography system, which consists of the model K2TS infrared camera that incorporates this clarity enhancement technology and the model K2TC image processing controller, allows for effective inline inspections using thermal images on production lines by acquiring and computing clear thermal images of moving objects, thereby contributing to improved inspection quality and productivity.

We will work on further performance improvements and consider expanding usage to applications where thermal images have not been used before.

References

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Author affiliation

Masanobu Masuda — IAP Development Department, Advanced Automation Company, Azbil Corporation

Susumu Nishisaka — CP Development Department, Advanced Automation Company, Azbil Corporation