A new technique of radiation thermometry using a consumer digital camcorder: Observations of red glow at Aso volcano, Japan

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We newly developed a technique of radiation thermometry using a Sony's consumer digital camcorder. Our system is not only convenience and cost effective but with a better performance than previous infrared thermometers, particularly in the place like a crater of volcano where is abundant in gas. This is because our system uses the submicron wavelength band, in which radiation is less influenced by absorption of gas than in the thermal infrared wavelength (>3 μm). We carried out observations of red glow at Aso volcano and succeeded in measuring the temperature of about 800°C, which is much more acceptable than previously reported values of 200–400°C. When we measure the temperature of about 300–700°C and 600–900°C in the place where is abundant in gas, using the camcorder with the near-infrared and with the visible wavelength mode is better than the thermal infrared region, respectively.

Key words: Thermometer, submicron wavelength, NightShot, red glow, Aso volcano.

1. Introduction

Thermal monitoring of volcanoes is very important and effective not only to understand underground geothermal systems but to detect precursory signals of future eruptions. Real-time monitoring has been carried out in many active volcanoes. Recently, satellite monitoring has succeeded in detecting large thermal anomaly (Rothery *et al.*, 1988) and some monitoring systems using GOES or ASTER are built up (Ramsey and Flynn, 2004). On the other hand, local and small anomalies, like fumaroles, cannot be detected by satellite, although they tell us the very beginnings of the coming eruption. Ground-based observations are useful for detecting such anomalies. Direct measurements of a thermocouple or a thermometer and remote sensing of a pyrometer or an infrared thermometer have brought about great success. Especially, infrared-video imaging instruments are rapidly developed and adopted all over the world.

Measurements using infrared thermometers, however, still have some problems. Getting exact value of temperature is one of the problems. In Aso volcano, Japan, some high temperature spots (red glow) have been observed since November 2000. Considering the spots were seen glowing red with the naked eye at night, the temperature of red glow must be at least higher than 500°C, but the value of 200–400°C was measured using an infrared thermometer by Japan Meteorological Agency (JMA) and Kyoto University. This low value can be due to the low spatial resolution of the thermometer or to the absorption of the infrared rays by water vapor and carbon dioxide from the fumaroles.

In order to avoid this effect, we measured the temperature of red glow with submicron wavelength band using a digital camcorder and succeeded in getting proper value. In addition, our systems have the advantage of the cost effectiveness and the convenience during field survey because a compact consumer camcorder was adopted as a thermometer. In this paper, we report our new technique of radiation thermometry and results of our observations.

2. Methodology

2.1 Advantage and disadvantage of the submicron wavelength band

We measured the temperature not with the so-called thermal infrared region (>3 μm), to which usual infrared thermometers are sensitive, but with the submicron wavelength region of the spectrum (<1 μm). According to Planck's law of the radiation, as temperature increases, the amount of energy increases at all wavelengths and the peak emission moves to shorter wavelengths (Fig. 1). Because of these properties of radiation, it makes a big difference to temperature measurements what wavelength the thermometer adopts. In the wavelength of 10 μm, which is longer than peak wavelength of energy radiated by black body with several hundred degrees C, radiation from an object with 300°C and 1000°C have the same order of magnitude. In the wavelength of 1 μm, which is shorter than peak wavelength, radiation from an object with 1000°C has six orders of magnitude more than that with 300°C. This indicates that measurement with 1 μm is less influenced by errors than with

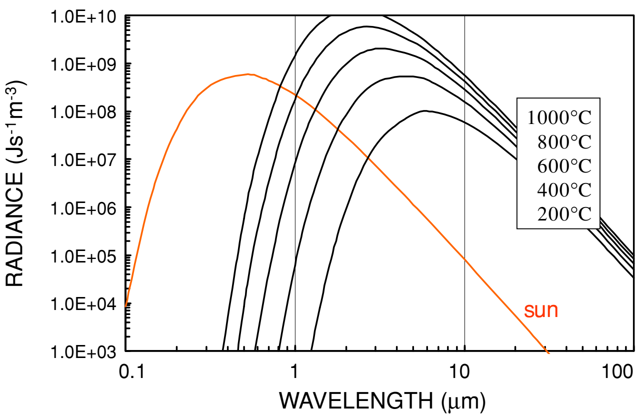

Fig. 1. Wavelength dependence of thermal radiance according to Planck's formula. Emmisivity of the radiating surface and transmissivity of the atmosphere is assumed at 1. The solar radiance at the Earth's surface is also shown.

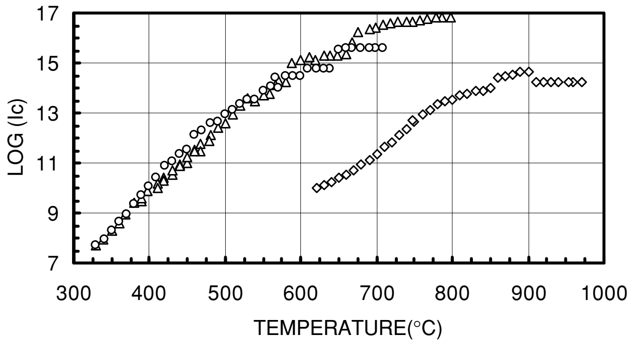

Fig. 2. The relationship between temperature and the corrected brightness in the normal camera mode (shown as diamonds) and in the NightShot mode with IR80 (shown as circles) and IR85 (shown as triangles).

10 μm in measuring temperature of an object with several hundred degrees C. Suppose that the atmosphere transmit only 30% of the radiated infrared rays, measurement of the temperature with 10 μm gives 300°C lower value, while 1 μm measurement gives values within 50°C.

Measurement with the submicron wavelength band, however, has one basic difficulty. In the submicron wavelength band, solar radiation is strong and not negligible. Solar radiation on the earth's surface is also shown in Fig. 1. In the wavelength of 1 μm, solar radiation on the earth's surface equals energy radiated by black body with 800°C in magnitude. This indicates that the temperature below 800°C cannot be measured using the wavelength of 1 μm in the direct sunlight, although we can avoid the influence of solar radiation at night. However, if solar radiation is weakened enough to detect the radiation of black body with several hundred degrees C, as in the cloudy day or in the shaded area, it is possible that the temperature of several hundred degrees C can be measured in the daytime.

2.2 Handycam with the NightShot

We adopted a Sony corporation's consumer digital camcorder (DCR-PC120), called Handycam, as a thermal camera with the submicron wavelength band. Recent consumer digital camcorders are compactly packed with high performance and are easily obtained all over the world. The CCD used in camcorders is natively sensitive to the band broader than the human eye, from the visible wavelength to the near-infrared wavelength of about 1 μm. Usually, the near infrared region is cut by the filter attached in the camcorder. Some Sony's Handycam has the NightShot mode. In this mode, the filter is switched off so that the CCD shows intrinsic sensitivity in the range between the visible and the near-infrared wavelengths. In addition, recent CCD with over one mega pixel resolution provides great detail and clarity. These indicate the Handycam with the normal camera mode and the NightShot mode can be used as a high resolution thermal camera with visible wavelength and with submicron wavelength, respectively. When we eliminate the influence of the visible light by using an infrared lowpass filter, the Handycam with the NightShot mode can be used as a near-infrared thermal camera in the daytime.

2.3 Using as a thermometer

The calibration experiment was carried out in order to examine performance of the Handycam as a thermometer. In a dark room, a rock sample was heated by an electric furnace up to 1000°C and shot from the small window at the door during cooling. We shot both in normal camera mode and the NightShot mode. In the NightShot mode, two types of the near-infrared lowpass filter (Hoya IR80 and IR85) were attached in front of the lens in order to cut the visible wavelength. IR80 and IR85 cut off the wavelength below 800 nm and 850 nm, respectively. Temperature of the sample was monitored by a thermocouple. The brightness of the sample was gotten from the recorded images and was corrected it as follows;

$$I_c = \frac{I_m^\gamma S}{10^{G/20}}$$

I_c: corrected brightness
I_m: measured brightness
γ: gamma value
S: shutter speed
G: gain.

I_m was read on a scale of 1 to 256 from grey-scale bitmap images. The gamma value was 2.2 for the standard of NTSC. The relationship between the corrected brightness and the temperature measured by a thermocouple is shown in Fig. 2. In the normal mode, the brightness increases proportionally with temperature between 600 and 900°C (shown as diamonds), while it does between 300 and 700°C in the NightShot mode (shown as triangles and circles). The difference among two filters attached in the NightShot mode is not recognized. We fitted curves to our data and got approximate expressions. On the basis of fitting curves, we developed the software, named ThermoShot, which converts a bitmap image into a thermal image. This enables us to measure the temperature of about 300–900°C with accuracy of about 20°C from the brightness of the object.

In this way, the Handycam equipped with the NightShot system is versatile because it works not only as a camcorder but as a thermometer. However, it has one inconvenience. In the NightShot mode, the camcorder adjusts shutter speed and gain automatically, although we can get the information of them after the recording because they are written in the tape. Therefore we cannot control the measurable range

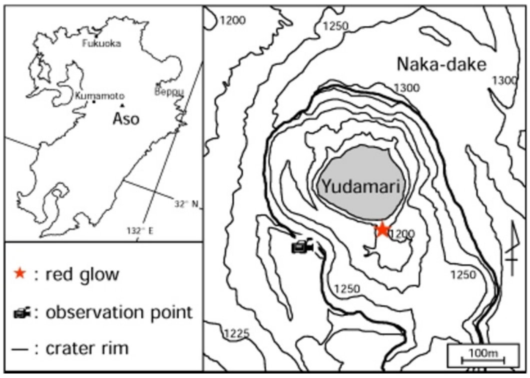

Fig. 3. Topographic map of the summit area of Naka-dake, Aso volcano.

at will. In particular, when the shot object is small, the camcorder adjusts shutter speed and gain for dark region and the object is taken as pure white. The temperature of the object is out of the measurable range.

3. Observations of Red Glow at Aso Volcano, Japan

Aso volcano is one of the most active volcanoes in Japan. Recent activities have been occurred at Naka-dake, one of the central cones in Aso caldera, and characterized by periodical Strombolian eruptions (Ono *et al.*, 1995). The 1st crater of Naka-dake is now occupied with light-green-colored hot water (called Yudamari), which is characteristic of dormant periods, and the next active period is expected to approach in the near future. On the southern wall of the 1st crater of Naka-dake, some glowing spots (red glow) have been observed since November 2000 (Fig. 3).

We carried out temperature measurement of red glow at Naka-dake in Nov 2001, Sep 2002 and Nov 2002. Red glow was observed from the point on the western crater rim, 230 m away in a straight line (Fig. 3). We tried to shoot by the Handycam in two different shooting modes with and without the near-infrared lowpass filter in the daytime and at night. JMA and Kyoto University also measured the temperature of red glow from the same place at the same time and reported the value of 200–400°C using an infrared thermometer (Monthly Report on Earthquakes and Volcanoes in Japan, 2002). This value seems to be underestimated because the thermometer operates at 8–13 μm and its angle of resolution is about 1°, which is two orders of magnitude lower than our system.

Representative images obtained by our observations are shown in Fig. 4. In the daytime, red glow could not be identified by observation with the naked eye or normal camera mode (Figs. 4(a) and 4(c)). Only the NightShot mode with filter was effective. When the region around red glow was subject to direct sunlight, no more than white images were gotten by shooting in the NightShot mode because the reflected ray of the sunlight was too strong. On the other hand, if the region was not subjected to direct sunlight, red glow was identified as bright spots by shooting in the NightShot mode with the filter (Fig. 4(b)). Toward evening, solar radiation weakened and the reflection on the ground decreased (Figs. 4(b), 4(d) and 4(f)). At night, clear images of red glow were gotten by shooting in the NightShot mode regardless of filter (Fig. 4(f)). Moreover, very bright spots could be shot by the normal camera mode (Fig. 4(g)). This indicates these spots have a high temperature above 600°C, which is the lower limit value of the normal camera mode.

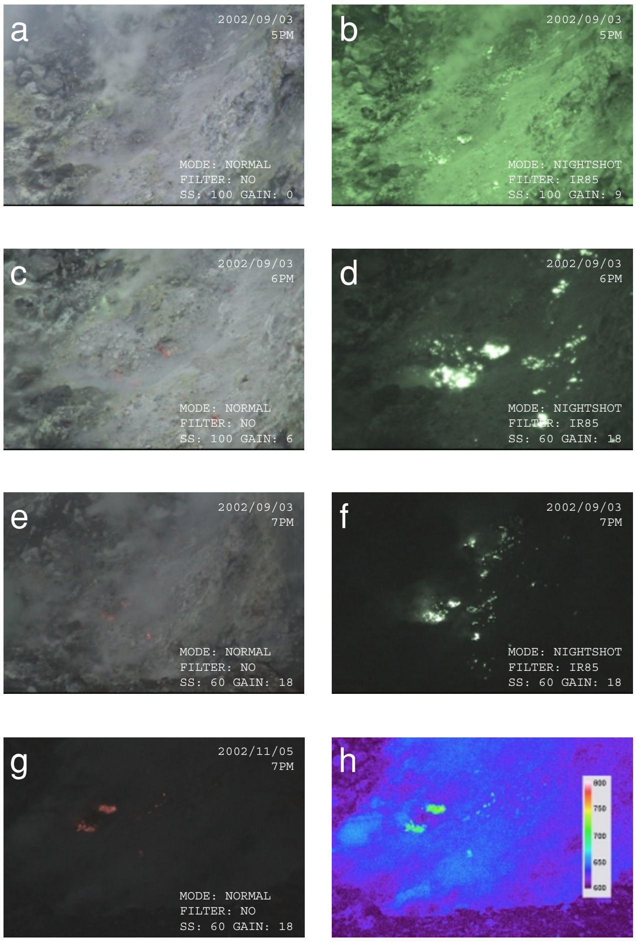

Fig. 4. Representative images of red glow at Naka-dake shooting by our camcorder system. Images (a, c, e, g) were shot by normal camera mode without filter. Images (b, d, f) were shot by the NightShot mode with a lowpass filter (Hoya IR85). Shutter speed (SS) and gain are also shown. Image (h) was a thermal image transformed from the image (g) by using ThermoShot. The brightest spots reached the maximum temperature of almost 800°C.

Temperature of red glow was assessed by using ThermoShot. In the NightShot mode, maximum temperature of red glow was out of the measurable range although low temperature region under 700°C was assessed. From the images shot by the normal camera mode, we got the value of almost 800°C (Fig. 4(h)). Even this value is probably underestimated because it is the pixel-integrated temperature (Rothery *et al.*, 1988) and the influence of the absorption by gas existed between red glow and the camcorder is unconsidered. However the value of 800°C is much more acceptable than previously reported values of 200–400°C. In this way, our system using a Sony's consumer digital camcorder is effective as a thermometer if the camera mode is selected in proper. Applicability of our system is summarized in Table 1.

Table 1. Applicability of the camcorder thermometer. Open circles and NA mean applicable and not applicable, respectively.

		Camera mode		
		NightShot	NightShot with filter	normal
In the daytime	In the sun	NA	NA	NA
	Out of the sun	NA	O	NA
At night		O	O	O
wavelength		0.3~1μm	0.8~1μm	0.3~0.8μm
measurable temperature		300~700°C		600~900°C

In addition to use as a thermometer, our system is effective in observing topography around the high temperature spots. The NightShot mode with the filter enables to shoot the background topography and the high-temperature spots simultaneously in the daytime (Fig. 4(b)). This is possible only when the background reflects the weakened sunlight and its brightness is within the measurable range of the camcorder. Such an observation may be helpful for study of high temperature fumaroles or prediction of next eruption because temperature rise and expansion of high temperature regions are one of the signals for eruption.

4. Conclusions

We presented a new technique of radiation thermometry using a consumer digital camcorder. Our system uses the submicron wavelength, with which temperature measurement is less influenced by errors than with thermal infrared wavelength (>3 μm). As a result of the calibration experiment, the normal camera mode using the visible wavelength and NightShot mode using the near-infrared wavelength of about 1 μm were effective for temperature measurement in the temperature range from 600 to 900°C and range from 300 to 700°C, respectively. We carried out observations of red glow at Aso volcano, Japan. As a result, high temperature region was identified if the camera system was set in proper. The maximum temperature of about 800°C was gotten by using our thermometry system. This value is much more acceptable than previously reported values of 200–400°C.

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Appendix.

Overall cost of our system is about $1000. You can keep the expenses below $500 if you select low-end camcorder. ThermoShot is posted on the following website.
http://www.gaia.h.kyoto-u.ac.jp/~thermoshot/index_e.htm

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