Remote Sensing Infrared Method of Detecting Near-underground Buried Objects by Means of Thermal Image Technique

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Abstract

The infrared radiometer method (T/IR) is widely used to detect invisible flaws of structural elements, as a remote sensing device. The thermal image technique is also carried out to analyze the location and dimension of internal flaws, like the crack, inclusion, separation and cavity. Those flaws are detected by visualizing the abnormal temperature distribution of the tested surface using solar, combustion and lamp heaters. The generated temperature distortion shows the location of the underground flaws imaged on the infrared radiometer.
Several proven methods, like radar electric resistance and magnetic flux, had been already used to detect their location of the buried objectives. Those methods are not remote sensing and spend the stupendous expense and plenty of time under the excavation. The T/IR method was applied to detect the near-underground buried structure of ancient remains, such as corner stone, settlement, shell mound and ancient tomb. It was remarked that the T/IR method was feasible to satisfy with those needs.
We examined to detect the buried ancient tombs and certified that tomb by observing non-uniform distribution of the infrared radiation temperature on the tested surface, as in case of test results using radar and electric resistance methods. It was concluded that the T/IR method was quite useful to detect the near-underground objects.

1 Introduction

The Remote Sensing device using the infrared radiometer (T/IR) was developed to detect the invisible internal flaws of the material and structure elements in many engineering fields. The thermal image technique based on the infrared radiometer is also carried out to analyze the location and dimension of invisible flaws of the materials, like crack, inclusion, separation and cavity. The T/IR studies on the detection limit and its analyses in the industrial and archeological underground objects are very little. (Okamoto, 1994a)
In this paper, those flaws are detected by visualizing abnormal temperature distribution of the tested surface above the internal flaws by means of the solar, combustion and lamp heaters. It was reported that the injected heat caused the distortion of the heat flow around the buried flaw that represented its location.
The preliminary detection tests of the model test piece were carried out and the heat transfer mechanism around the flaw was analyzed numerically. It was obvious throughout a series of the analysis that the proposed T/IR method was useful to detect the invisible near-underground objects as the remote-sensing device.
Generally, ancient remains and artificial engineering structures are occasionally in the ground and they are invisible on the surface. Several proven exploration methods, like radar, electric resistance and magnetic field, have been used to detect their location and dimension of the buried object. Those methods are not remote sensing and limited in a small area of the ancient remains. Therefore, we spend the stupendous expense and plenty of time under excavation. In Japan, there are a lot of the ancient remains over 300,000. Recently, many remains

were often found on the spot of civil and architectural construction and so on. (Okamoto, 1995b)

The few thousand of those remains that bear the stupendous expense of about 200 million dollars per year and plenty of time are now going on under the excavation. So, it is needed to develop a new detecting method feasible to conduct by speedy, automatic and remote sensing method. We propose a noble T/IR method with combination of the existing methods for this purpose.

In this paper, the T/IR method was applied to detect the near-underground objects of the ancient remain, like corner stone, stone settlement, shell mound and ancient tomb. As the application study, we verified the existence of the buried conical tomb by observing non-uniform temperature distribution, as in case of the radar and electric resistance methods. (Okamoto, 1995b)

Finally, the thermal image test using the T/IR method is one of the non-destructive and remote sensing diagnosis methods. And we certify that this method is useful to detect the near-underground remains. (Okamoto, 1995c)

2. Experimental and Numerical Modeling Test

2.1.Test methods

Thermal image method represents that a distortion of the transient temperature distribution around the flaw using the infrared radiometer certifies the invisible flaw included in the space. This distortion of the transient temperature is generated by a difference of the thermal permeation speed between the space and flaw in case when thermo-physical properties of both materials are different with each other. (Inagaki, 1995)

The preliminary modeling tests using sun, high-temperature radiation and combustion heaters are prepared for practical investigation. The solar heater injects heat energy on the ground, maximum heat flux of which is 500 w/m^2. The high-temperature radiation heater consists of the stainless pipe with a stainless parabolic mirror. The combustion gas of 1000 ^{0}C flows in the pipe and radiates the radiation energy on the ground. Maximum heat flux is half of the sun. The oil-burning heater represents that the corrugated paper containing the oil is sprayed and burned on the ground. The heat flux of the oil-burning heater is 5 kw/m^2. The radiation temperature distribution of the surface is measured by the infrared radiometer at constant time interval.

The polystyrene test plate is installed in the ground and the temperature in the ground is measured by the Chromel-Alumel thermocouple of 0.5 mm in diameter.

2.2 Test Result

Figure 1 shows the transient temperature around the buried plate of H=10 cm deep. The infrared radiometer and thermocouples measure the temperatures of the surface T_1 and soil T_2, T_3. The injected solar energy increases the temperature of the surface T_1 in daytime. T_1 decreases in the evening by sky radiation. The temperatures of the soil T_2 and T_3 are larger than T_1 and atmospheric temperature of T_a.

Figure 1 Transient temperature around the buried plate (depth H=10 cm)

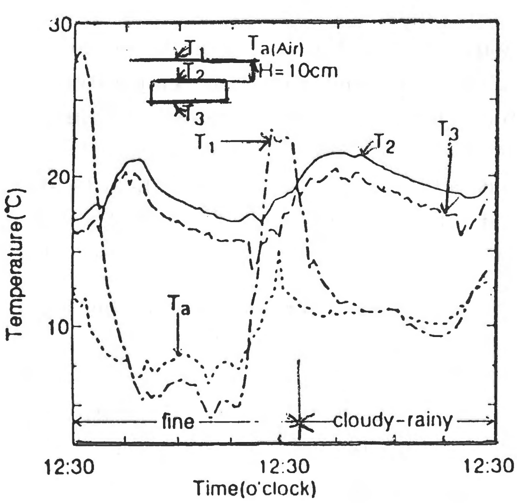


Figure 2 Experimental and numerical temperatures of the buried plate (depth H=15 cm)

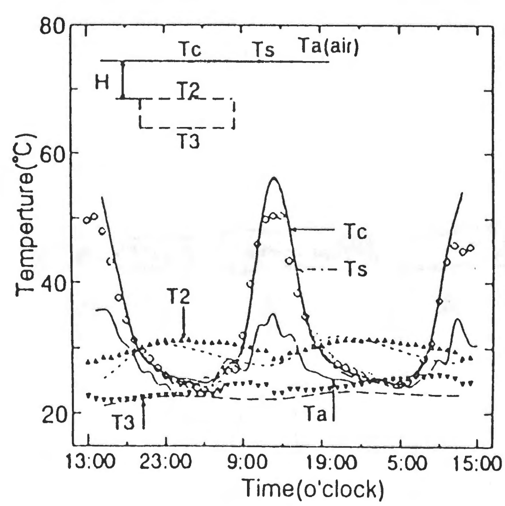


Figure 2 shows the transient experimental and numerical temperatures of the buried plate of H=15 cm in deep. The two temperatures are nearly similar to each other. The numerical calculation represents that the two-dimensional calculated result is possible to simulate the experimental result.

The high-temperature radiation heater radiates the heat on the surface of the tested soil during 20 minute and we observe the different radiation temperature zone above the buried plate of 10 cm deep using the infrared radiometer during cooling process.

Figure 3 represents the thermograph of the deep buried styrene plate of 40 cm in deep by the oil burning method. After burning time of 5 minute, we discriminate the high temperature zone above the internal flaw. As the injected heat flux is higher than that of the solar and high-temperature radiation heaters, the oil-burning heater can detect the deep buried flaw of 40 cm deep.

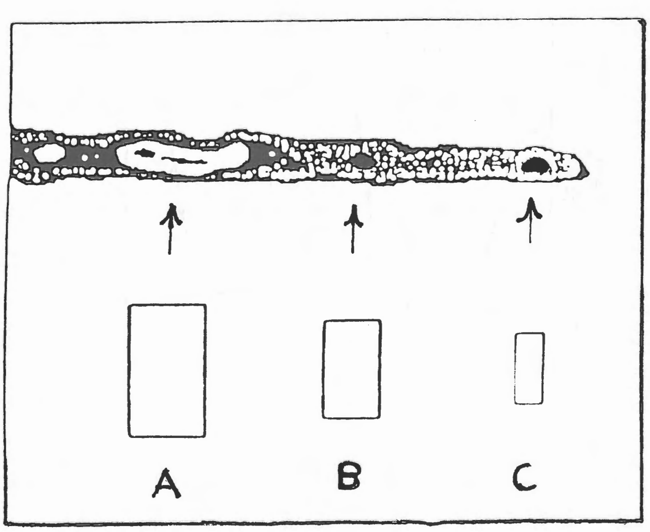
Generally, the generated temperature difference caused by the buried model plate is decreasing with increase in the depth of the buried flaw. On the other hand, time delay, which shows the maximum and minimum temperature difference, is increasing with increase in the depth of the buried flaw.

Table 1 represents summary results of the detection limit and injected heat flux for three heaters used. The detective depth of the buried modeling plate is increasing with increase in the injected heat flux.

Lastly, experimental and numerical modeling tests clarify that the thermal image method is useful to detect the buried near-underground object in the soil.

3. Detection of Near-underground ancient tomb

Figure 3 Thermograph of the deep buried plate by the oil burning method. (depth H=40 cm)



3.1 General description

As an application study, the thermal infrared radiometer, near-infrared and visible cameras are used to detect the underground ancient tombs, named Tajiri and Saitobara remains, that were buried in exploded ash by explosion of volcanoes founded by Japan Science Foundation. (Okamoto, 1997d)

3.2 Test result of Tajiri remains

We participated the exploration test of the Tajiri remain buried in the volcano ash by explosion of Mont. Haruna at 6 century. Tested area is 50 meter in square.

It was already performed to search the near-underground conical tomb using the radar, magnetic and electric resistance method. Those methods estimated that the near-underground conical tomb surrounded by the heap and round path were located at the center. (Okamoto, 1997e)

The thermal infrared radiometer, near infrared and visible camera were settled on the roofing frame of a conventional car. We measured the surface of the test field from morning to evening at constant time interval and took the photograph using respective cameras.

We could not detect the under-ground tomb using the visible colored camera with RGB filters. In case when we used the near-infrared camera, we could confirm the white field above the tomb on the photograph, because water content of the soil above the tomb is smaller than that of the soil without the tomb, as shown in Figure 4.

The measured thermograph using the infrared radiometer represented the higher radiation temperature field above the tomb than that not influenced by the tomb, as shown in Figure 5. (Okamoto, 1997e)

Figure 6 represents the field of brightness by the near-infrared camera and radiation temperature by the infrared radiometer of the testing field at Tajiri remains. We could visualize the high-temperature field by the infrared radiometer (TI/R) and light field by the near-infrared camera (NI/C) at the head of the cone tombs and its surrounding heap. Otherwise the low-

Table 1 Injected heat flux and detection limit for three heaters

used heaters	injected heat flux (kw/m^2)	detective depth (cm)
sun	0.5	20
radiation	0.25	10
oil- combustion	5	40

temperature field by the TI/R and dark field by the NI/C were observed round the center tomb.

Figure 7 represents the forecasting maps of the buried remains by radar, electric resistance and infrared tests. We can discriminate the fields of the fringe distortion by the radar test, that of the high electric resistance by the electric resistance test and that of the radiation temperature difference by the thermal infrared test respectively. That map is quite similar to each other and certifies the location of the buried tomb and its surrounding heap. (Kamei, 1995), (Akabane, 1996)

In order to verify the detection limit of the buried tombs, the thermal image method was applied to analyze temperature distribution around the tomb. Table 2 shows the thermo-physical property of the volcano ash

Figure 4 Near-infrared photograph of test field

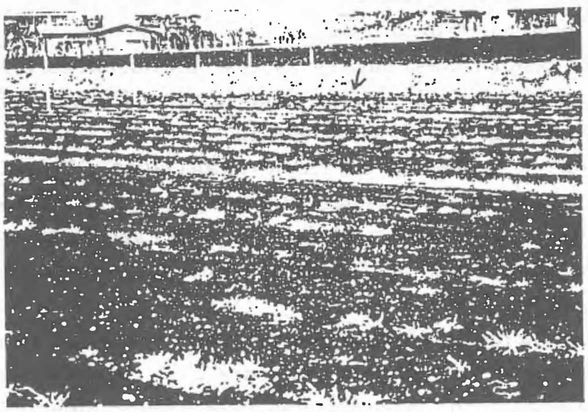


Figure 5 Infrared thermograph of test field

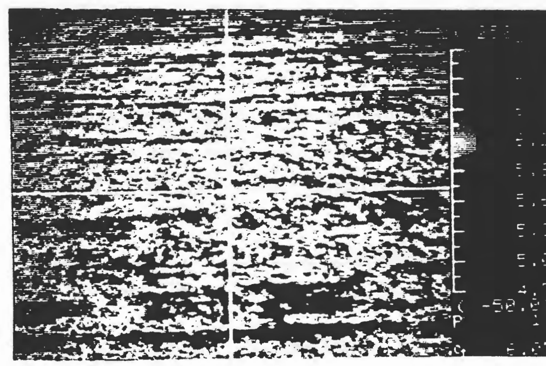
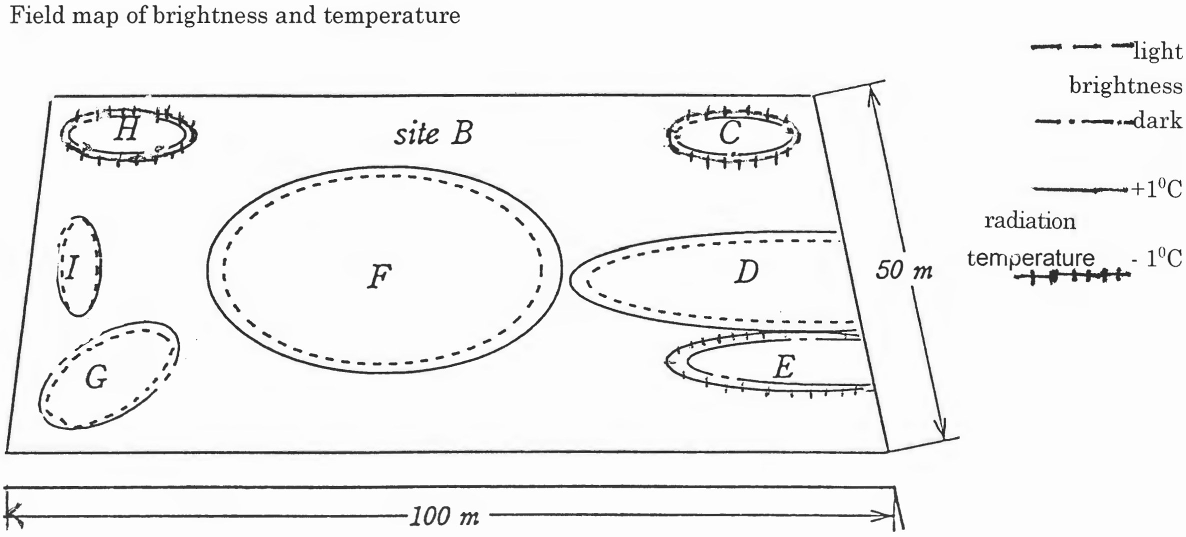


Figure 6 Field map of brightness and temperature



and black soil. Those data obtained by measuring the materials sampled in the testing field.

Figure 8 represents a proposed two-dimensional model of the buried tomb for our numerical calculation. Solving the two-dimensional heat-balance and its boundary-condition equations, the transient temperature distribution around the buried tomb was derived numerically.

Figure 9 represents the calculated temperature of the buried tomb of H=10 cm deep. Surface temperatures above the tombs and apart from the tomb T_c and T_3 are increasing by solar heating in daytime. The temperature T_c becomes larger than T_3 in daytime and smaller than T_3 in the evening, because of the thermal expansion and contraction flow around the tomb.

So the temperature difference between T_c and T_3 $\triangle T_c$ becomes positive in the daytime and negative in the night. That temperature difference $\triangle T_c$ is generated by the thermal flow around the buried objects, which causes difference of the thermo-physical properties of the soil and volcano ash.

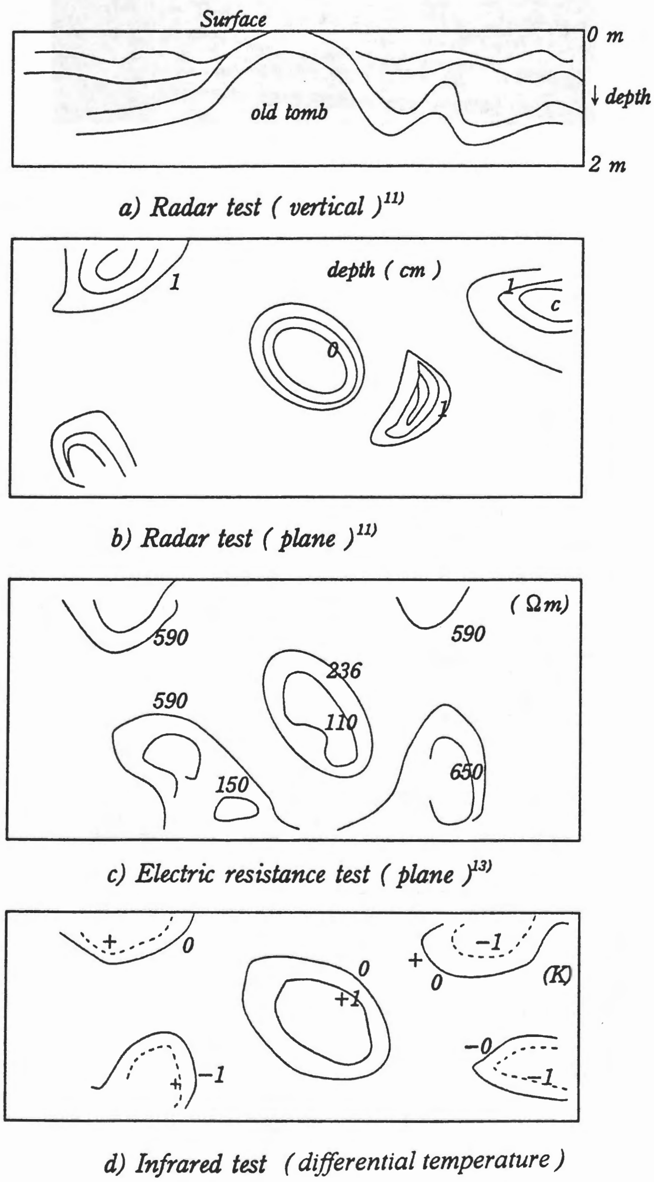
Miura measured the surface temperature and water content of the tested soil. The measured water contents of the soil above and without the tomb were 8 and 9.5% respectively. (Miura, 1995)

The result shows that the thermal flow distortion and dry out of the soil cause the temperature difference $\triangle T_c$ by the solar heating in the daytime.

Table 3 represents the result of calculation $\triangle T_c$ with depth H as a parameter. The temperature difference $\triangle T_c$ becomes small and the time which generates the maximum value of $\triangle T_c$ delays with increase in the depth H.

The test results of the numerical analysis represents the calculated temperature difference $\triangle T_c$ certifies the generation the experimental temperature difference above the tomb, as already shown in Figure 8.

Figure 7 The forecasting maps of the buried remains by radar, electric resistance and infrared tests. (Kamei, 1995), (Akabane, 1996), (Okamoto, 1997e)



a) Radar test (vertical)[11]

b) Radar test (plane)[11]

c) Electric resistance test (plane)[13]

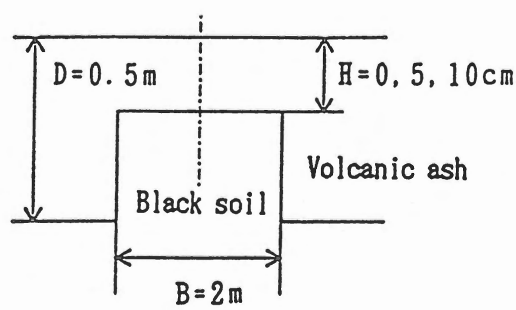
d) Infrared test (differential temperature)

3.3 Test results of Saitobara tomb

Table 2 The thermo-physical properties of black and soil

Item	black soil	volcanic ash
Relative weight (kg/m^3)	1230	1160
Specific heat (kJ/kg · K)	0.76	0.84
Thermal conductivity (kJ/m · K)	1.05	0.95

Figure 8 Numerical calculation model



The second test was carried out to detect the location of the vertical hole of the buried tomb with vertical and horizontal holes, named Saitobara ancient remain. The visible and infrared cameras were used, as shown in Section 3.2.
Figure 10 shows the infrared thermograph of the ground surface of the buried tomb. We can discriminate the higher temperature zone above the vertical hole of the tomb.

4. Conclusion

The infrared thermal image method using solar, high-temperature radiation, combustion heaters was used to detect the buried underground objects and their detection limit was estimated numerically and empirically by modeling the underground structure. It is obvious throughout a series of analysis and experiment that thermal image method is useful to detect the buried underground structure laid down in the ground.
As an application study, the infrared radiometer was used to detect the near-underground ancient tombs. It is clarified that radiation temperature measurement using the infrared radiometer is quite useful to detect the near underground remain, as the remote detecting device.

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Figure 9 Calculated temperature of the buried tomb (depth of H=10 cm)

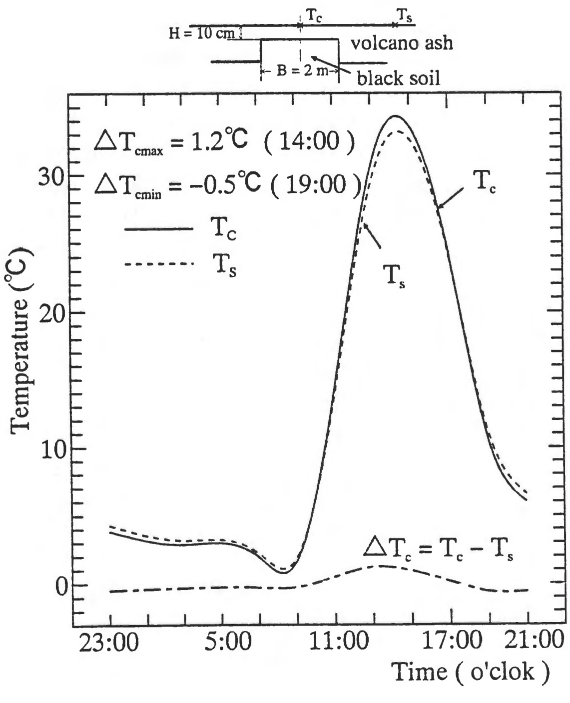

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Table 3 Results of calculation with depth H as a parameter

H (m)	ΔT_{cmax} (^{0}C)	τ_{max} (o'clock)	ΔT_{cmin} (^{0}C)	τ_{min} (o'clock)
0	1.0	13.00	0.6	19,00
5	0.5	15.00	0.2	21.00
10	0.3	17.00	0.1	23.00

Figure 10 Thermograph of Saitobara tomb