Correlativity analysis between image gray value and temperature based on infrared target

Gong Jiamin[1], Guo Tao[1], Cao Yi[2], Liu Huabo[3], Wang Beibei[4]

(1. School of Electronics Engineering, Xi´an University of Posts and Telecommunications, Xi′an 710121, China;
2. School of Marine Science and Technology, Northwestern Polytechnical University, Xi′an 710072, China;
3. School of Science, Xi´an University of Posts and Telecommunications, Xi′an 710121, China;
4. School of Communication and Information Engineering, Xi′an University of Posts and Telecommunications, Xi′an 710121, China)

Abstract: By using the correlativity between image gray value and temperature, the temperature that is hard to measure can be accurately obtained in some fields. The correlativity analysis between image gray value and temperature was proposed based on infrared target (IT). Self-developing infrared target was taken as a research object, which was a method to collect the infrared images which were taken at different temperatures (60-110 ℃) by infrared target with circular apertures. Matlab was used to extract the infrared image gray values (IIGV) of certain regions at different temperatures, which could ensure the correlativity between infrared target image gray value (ITIGV)and its temperature. The correlation coefficient of 0.962 was obtained. Experimental results reveal a good linear correlation between the average gray value of area of interest (AOI) in the infrared target images and temperature. With the change of infrared target temperature, infrared image gray values has changed. Both of them show a good linear correlation. The correlativity between image gray value and temperature based on infrared target has an outstanding effect on straw self-ignition in paper mill, medical security, road construction, etc.

Key words: IIGV; correlativity; stacking temperature monitoring; non-invasive temperature measurement; temperature field

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红外靶标的图像灰度与温度相关性剖析

巩稼民[1],郭 涛[1],曹 懿[2],柳华勃[3],王贝贝[4]

(1. 西安邮电大学 电子工程学院,陕西 西安 710121; 2. 西北工业大学 航海学院,陕西 西安 710072;
3. 西安邮电大学 理学院,陕西 西安 710121; 4. 西安邮电大学 通信与信息工程学院, 陕西 西安 710121)

摘 要: 通过图像灰度与温度的相关性,可以精确地得到一些领域上难以被测量到的温度。提出了基于红外靶标的图像灰度与温度的相关性分析。以自行研制的红外靶标为研究对象, 采集带有圆形目标孔的红外靶标在不同温度(60~110 ℃)下的红外图像, 再利用 Matlab 提取不同温度下特定区域的红外图像灰度值,从而确定红外靶标图像灰度与其温度的相关性,得其相关系数为 0.962。实验结果表

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作者简介:巩稼民(1962-),男,教授,硕士生导师,博士,主要从事光通信技术、非线性光学方面的研究。Email:gjm@xupt.edu.cn

通讯作者:郭涛(1989-),男,硕士生,主要从事光信息传输技术方面的研究。Email:guotao_strive@163.com

明：红外靶标图像中 AOI(area of interest)的平均灰度与温度存在明显的相关性，当红外靶标的温度发生变化时，其红外图像灰度也随之发生变化，且两者呈良好的线性关系。基于红外靶标的图像灰度与温度的相关性在造纸厂草料自燃研究、医疗安全、道路施工等方面都有着较好的应用。

关键词：红外图像灰度； 相关性； 堆垛温度检测； 无创测温技术； 温度场

0 Introduction

The correlativity analysis between the image gray value and temperature[1-2] has always been a research focus. The key of the study is how to obtain the highest correlativity. In the past, experts take animal organs, material objects and others, as the objects of study, which achieve quite good results and propose some new and advanced operating methods for several fields. The correlation coefficient between image gray value and temperature based on animal organs is 0.895 [3]. However, there are some limitations, for instance low precision, complex operating process, high labour cost and so on. This article proposed a new method of correlativity analysis between image gray value and temperature. This method has the characteristics as high precision, easy operation, economizing manpower and solves lots of significant problems in practical projects. According to initial researches, they have a high precision in temperature measurement that is involved in straw self-ignition in paper mill [3], medical security [4], road construction[5], etc. Because of the limitations of traditional techniques, it is not easy to precisely measure temperature in these areas.

Heat therapy technique frequently plays an important role in medical security. Non-invasive temperature measurement technique [3] is the core technology in heat therapy technique. The method proposed in this article will provide powerful technological supports to non-invasive temperature measurement technique. And it can make non-invasive temperature measurement technique more effective and safer. In China, there still exist many security threats in raw material stockpile management[6] in paper mills, especially the paper mills that use straw as raw material, most of them have broken out fires. These are all because there is no appropriate temperature measurement equipment. However, the new equipment can be used to get perfect real-time feedbacks about the stacking temperature[7]. When stacking temperature is approaching self-ignition temperature, the staffs can take effective measures to prevent fires in time. Because the test of pavement temperature field[8] is the key factor to choose asphalt mixture in road construction, temperature test is especially important. Traditional method is to drill the pavement for inserting temperature sensor. This method is no only severely destructive to pavement, but also damage the temperature sensor easily, which will lead to critical measuring errors and manpower waste. By using the new method, the temperature field distribution of road pavement[9] can be accurately measured. The measure not only saves the labour cost, but also has no harm to the pavement. Therefore, the security and success of road construction can be ensured.

1 Experimental model and method

1.1 Experimental model

Experimental system mainly consists of infrared detector and IT[10]. Experimental system model is shown in Fig.1.

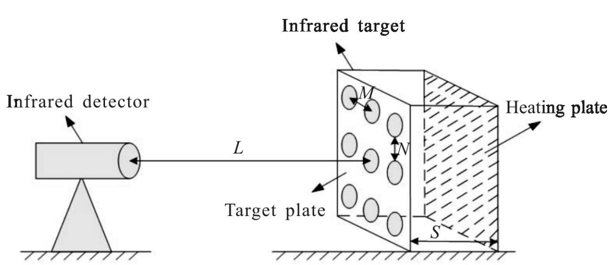

Fig.1 Experimental system model

Gobi-384 infrared camera produced by Belgium XENICS Company was used as infrared detector, which is made up of infrared lens, focusing ring, rotary adjustable aperture, aperture lock nut and focus lock nut. The camera output interfaces have PAL interface, CameraLink interface and network interface, pixel size is 25 μm, and the camera has a good image quality, as displayed in Fig.2. The captured images can be saved as files for analyzing the images subsequently. The IT is the self-designed target, as shown in Fig.3. Moreover, it has already been applied for the patent (patent number: CN 201420683565X). IT consists of the main structure of target and controller. Heating plate, target plate and outer frame compose the main structure of target. There are power supply interface, temperature sensor interface and heating plate interface on the controller. The controller can control the temperature of heating plate from 1℃ to 140 ℃.

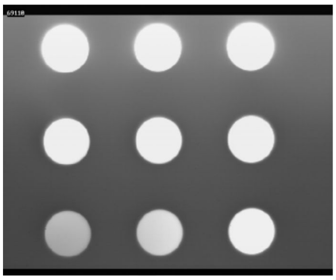

Fig.2 Infrared target image

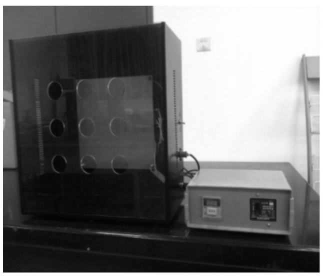

Fig.3 Infrared target

1.2 Experimental method

Before the experiment, the distance L from infrared camera to the center of target plate is 2 m, the distance S from heating plate to target plate is 20 cm, the distance M between the centers of two adjacent circular apertures is 10 cm, and the distance N between two circular apertures is 5 cm. When the controller turn on the heating plate[11], infrared camera record and save the IT images at 1 ℃ intervals. When the temperature of heating plate is slowly rising from 60 ℃ to 110 ℃, infrared camera records and saves a series of IT images at different temperatures. The following step is to process target images and then extract image gray values at different temperatures, which can ensure the correlativity between ITIGV and temperature.

Ultimately, it is important to use Matlab to extract the gray values of 50 images (768×576 pixels) that are taken from 60℃ to 110℃ by infrared camera[12]. The infrared images that are taken by infrared camera are 256 grayscale images. In this experiment, only gray value of central circular aperture in the target plate can be chosen and analyzed. The target plate is composed of glass, which has a shielding effect on the infrared rays, therefore, only the image of circular aperture can truly reflect the target temperature. The temperature sensor probe touches the center of heating plate. Consequently, there is an accurately corresponding relationship between the circular aperture image in the target center and temperature. The accurate correlation between gray value and temperature can be achieved by analyzing the gray value of central circular aperture. At last, using Matlab to draw the final curves of gray value and temperature and fitting the measured curve can ensure the correlativity between target gray value and temperature[13].

2 Experimental result and correlative analysis

In order to analyze the correlation between ITIGV and temperature, choosing 65×65 pixels from circular aperture image in target center and then taking the average gray value of these pixels can get the average gray value of target central circular aperture image, which could ensure the corresponding relationship between image gray value and temperature.

First of all, it is important to assure whether image gray value and temperature based on IT have correlativity or not. What kind of relationship is between them if there is a correlation? In the experiment, the relation curve between the average gray value of target central circular aperture image (grayscale) and temperature (℃) is achieved, as shown in Fig.4. Table 1 shows the relation curve slopes between target gray values and temperatures in the different temperatures ranges. Figure 4 shows that ITIGV have a certain correlation with temperature. The target gray value increases with the increase of temperature. Table 1 shows that the relation curve slopes between average gray value of target central circular aperture and temperature in different temperature ranges are pretty close and both are more than zero. According to the analysis, image gray value and temperature based on IT have a linear positive correlation.

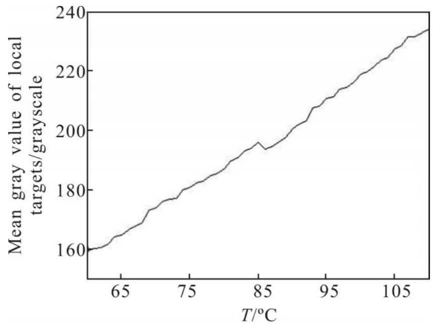

Fig.4 Relation curve between average gray value of target central circular aperture image and temperature

Tab.1 In different temperature ranges, the relation curve slopes between average gray value of target central circular aperture and temperature

Temperature range/℃	60-70	70-80	80-90	90-100	100-110
Slope	1.483 1	1.457 8	1.573 5	1.601 5	1.532 9

Secondly, it is necessary to analyze the close-degree of correlativity between ITIGV and temperature. They show a linear positive correlation in accordance with previous analyses. Hence, using correlation coefficient to reflect the close-degree of correlativity between image gray value and temperature is advisable. The formula of correlation coefficient is:

$$r=\frac{n\sum xy-\sum x\sum y}{\sqrt{n\sum x^2-(\sum x)^2}\sqrt{n\sum y^2-(\sum y)^2}} \qquad (1)$$

In Eq.(1), n is the number of data groups, x is target temperature, y is average gray value of target central circular aperture. Discrete data target temperature (℃) and image gray value (level) measured by the experiment are put into the above formula, the correlation coefficient can be get and it is 0.962. The correlation coefficient r=0.962. $0.8<|r|<1$, hence ITIGV has a highly linear correlation with temperature.

Then, the mathematical formula of correlativity between ITIGV and temperature, which also called the regression equation , will be analyzed. Because ITIGV is highly correlated with temperature, unitary linear regression analysis is used. Unitary linear regression model is:

$$y_c=a+bx \qquad (2)$$

In Eq.(2), y_c is the estimated theoretical value of the dependent variable, x is the actual value of independent variable, a and b are undetermined parameters. In this paper, the target temperature is the independent variable x, image gray value is dependent variable. Intercept a is the average effect on the image gray value that is affected by various factors except target temperature. Regression coefficient b shows that image gray value changes b grayscales on average with the target temperature changing each degree Celsius. Parameters a and b can be calculated by the following formula:

$$\begin{cases} b=\dfrac{n\sum xy-\sum x\sum y}{n\sum x^2-(\sum x)^2} \\ a=\dfrac{\sum y}{n}-b\dfrac{\sum x}{n} \end{cases} \qquad (3)$$

Substituting the measuring data in Eq.(3) can get a= 66.550, b =1.514. The regression equation is: y_c = 66.550+1.514x.

The coefficient of determination R^2 =SSR/SST. SST is the sum of square of total variation. SSR is the sum of square of regression. After calculation, R^2= 0.925, it is shown that 92.5% ITIGV variability is caused by target temperature. Figure 5 shows the regression line and measured curve. By comparison, the regression line can reflect the changing of measured curve properly.

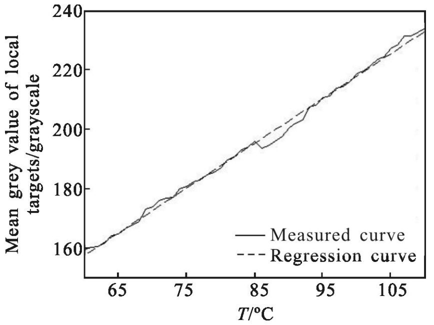

Fig.5 Measured curve and regression curve between average gray value of target image and temperature

The following step is to analyze the standard error of estimation of the unitary linear regression analysis. The standard error of estimation is a statistical analysis index that can explain the representativeness of regression equation, which is the average error of the actual measured value and theoretical value. The smaller value is, the stronger representativeness of regression equation becomes and the more accurate result that is predicted by regression equation will be. The formula is:

$$S_{yx}=\sqrt{\frac{\sum y^2-a\sum y-b\sum xy}{n-2}} \tag{4}$$

Substituting the experimental data in Eq.(4) can obtain S_{yx}=1.238 8. There are gray value differences of 1.238 grayscale between the measured value and estimated value. This error is quite small compared with the average gray value of target image from 160 to 235. It shows that the gray value that is estimated by target temperature has a strong representativeness in actual measured gray value. In conclusion, there is a highly linear correlation between ITIGV and temperature.

3 Application

3.1 Correlativity between image gray value and temperature in the application of straw self-ignition in paper mill

In China, there are security threats in raw material stockpile management in many paper mills. Most of paper mills that use straw as raw material have broken out fires. Fire disasters occur because of the pyrophoricity, suddenness and variability of straw[3]. Without the fire sources, heat dissipations of combustible materials are hindered, which result in the accumulating heat and increasing temperature. When the temperature exceeds its threshold, it will give rise to spontaneous combustion, which is its pyrophoricity. Consequently, it′ s crucial to control the straw temperature for preventing the straw self-ignition. Allowable temperature values are shown in Tab.2.

Tab.2 Allowable temperature values and measures

Danger level	Storage tempera-ture/℃	Influence and harm degree	Measures
More danger	60-70	Edges of the accident state, has the fire risk	Key monitoring, real-time temperature measuring, strict management and control
Danger	70-90	Temperature, bad ventilation fire easily	Cirb, dismantled before prepared to fire, to prevent spontaneous combustion and fire spread
Disaster	>90	Danger of the fire is very large	In addition to the use of these measures, if within the crib coking seriously, see the fire smoke, first with water, after the crib

In order to monitor the stacking temperature, traditional method is to set line-type thermal detector in stacking and to build temperature measurement sensor network[7]. However, there are some shortcomings, such as the low extensibility, complicated wiring and simply aging lines that are easily corrupted and destroyed in fires. Nowadays, the new method is used to analyze the stacking infrared image, which can ensure the temperature field distribution [6]. Infrared CCD is applied to take real-time pictures on stacking, then analyzing the IIGV and calculating the temperature values by using the correlativity between gray value and temperature, which can improve the reliability of real-time temperature measurement system and reduce costs. This method accurately reflects the stacking temperature by analyzing the stacking image gray value. When the monitored stacking temperature reaches its highest warning temperature, it is effective to take measures to dissipate heat promptly, which can avoid the fires effectively.

3.2 Correlativity between image gray value and temperature in the application of medical security

Invasive temperature measurement technique[3] is used widely in clinical practice. This technique directly inserts thermosensitive devices such as thermocouple and thermistor into the testing parts to measure the temperature directly. Since the method of invading tumor for measuring temperature is quite dangerous and has many technical weaknesses, it is necessary to find a non-invasive temperature measurement technique. In recent years, there are a few reports about non-invasive temperature measurement in cancer heat therapy in the world. To sum up, the methods include microwave temperature measurement, NMR (nuclear magnetic resonance) temperature measurement, impedance temperature measurement, computer model of temperature field and ultrasonic temperature measurement. An effective heat therapy needs to control the temperature of the healed tissues in an appropriate range. In order to kill cancer cells without damaging normal tissues, it is significant to measure the temperature of tissues accurately. It has direct impact on the effects of the cancer heat therapy. Microwave heat therapy is a vital technique of treating tumor. Microwave is to heat tumor tissues above its heat resistance (43 ℃) for killing the cancer cells by using some heating method. When the temperature of tumor is measured and controlled, the new method is to use miniature infrared camera to take real-time photos of tumor and then analyze the image gray values to ensure the temperature of the tumor compared to Fig.6 and Tab.3, which not only greatly decreases the risk of surgery but also increase the success rate of the surgery.

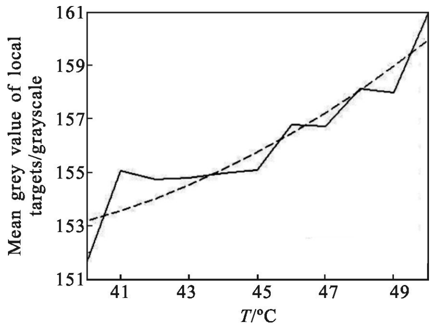

Fig.6 Measured curve and the fitted curve between average gray value of target image and temperature

Tab.3 Average gray values at different temperatures

T/℃	Gray value/grayscale
40	153.589
41	155.057
42	154.728
43	154.728
44	154.972
45	155.072
46	156.788
47	156.730
48	158.116
49	158.968
50	160.969

3.3 Correlativity between image gray value and temperature in the application of road construction

The choices of materials directly affect the qualities of entire highway projects in road construction. Hence it is a key issue to choose appropriate asphalt mixture. Distribution and variation of pavement temperature field [14] can help analyze the formation mechanism of various damages of asphalt pavement and assure the strength parameters of asphalt pavement [15]. According to these parameters, it is feasible to select the appropriate asphalt mixture and ensure the quality of road construction.

Currently, the Diefenderfer regression statistical analysis model [5] is popularly applied in research of asphalt pavement temperature field. There are some following requirements in embedding sensor in the measuring part of temperature field. Firstly, to choose some easily accessible places to embed the sensor except in roadway; Secondly, to pre-embed the sensor in the building roads and protect it from any future construction damage; Thirdly, to drill the built road for inserting the sensor and repair the pavement after measuring well, etc. Finally, using resistance temperature conversion formula[8] calculates the temperature value. The platinum resistance temperature conversion formula is:

$$y=A\times(Bx-C)-D \tag{5}$$

In Eq. (5), y is pavement temperature, x is the resistance value of Pt-resistance, A, B, C and D are the corresponding parameters.

The above methods require artificial real-time records on the spot, which are quite costly in labour. Nowadays, the new method is to use infrared camera to take pictures of the pavement and obtain the accurate pavement temperatures in accordance with the correlativity between temperature and gray value, which can omit the tedious steps. In addition, effectively adjusting the field-angle of camera can measure more road areas. Simultaneously, it is more effective to use lots of cameras and make their field-angles cover the whole measuring pavements, and then analyze the gray values of pavement infrared images, which can achieve the pavement temperature field distribution compared with the correlativity between image gray value and temperature. It is more efficient than the traditional method of measuring temperature field. The new method can save manpower and raise the range of measurement.

4 Conclusions

Theoretical analyses and experimental results in this paper show that ITIGV and temperature have an excellent correlativity. Therefore, it is quite feasible to collect and analyze the temperature in straw self-ignition in paper mill, medical security, road construction, etc. by utilizing the correlativity between ITIGV and temperature. Only using this method can precisely receive the temperature profiles in the studying region. This method is more precise and more concise than the existing temperature measurement technology. Generally speaking, it is feasible to use the correlativity between ITIGV and temperature to measure the temperatures in straw self-ignition in paper mill, medical security and road construction. However, there still exist many issues in applying this method to the practical projects. This paper verifies the feasibilities of this method in some certain extent. In the future, the deeper research is necessary for improving theory and experiment.

References:

[1] Cai Yi, Hu Xu. State of theart and future trend of detectors for infrared imaging seekers [J]. ***Infrared and Laser Engineering***, 2006, 35(1): 7-11. (in Chinese)

[2] Luo Yuan, Wu Caiming, Zhang Yi. Facial expression feature extraction using hybrid PCA and LBP [J]. ***The Journal of China Universities of Posts and Telecommunications***, 2013, 20(2): 120-124. (in Chinese)

[3] Yu Bo. The current difficulties and countermeasures facing the fire supervision and management work [J]. ***Science and Technology to Guide***, 2010(7): 138-139.

[4] Ren Xinying, Wu Shuicai, Du Xu, et al. The study on the relativity of B mode ultrasound image gray and temperature in tissue [J]. ***Beijing Biomedical Engineering***, 2004, 23(2): 116-118. (in Chinese)

[5] Sui Xianghui. The prediction and application of asphalt pavement temperature field [D]. Xi'an: Chang'an University, 2007. (in Chinese)

[6] Wu Xiaoyan. Analysis of reed yard fire safety status and fire prevention measures[J]. ***China Foreign***, 2008(10): 234-235. (in Chinese)

[7] Huang Yani, Zhong Jianjun. An analysis on induced factors and prevention measyres of fire accidents in reed yard for a paper mill [J]. ***Journal of Chinese People's Armed Police Force Academy***, 2014, 30(10): 59-61. (in Chinese)

[8] Zhang Yunlong. Monitoring and promote techniques of construction quality for asphalt pavement [D]. Chongqing: Chongqing Jiaotong University, 2014. (in Chinese)

[9] Wang Huawei. Research on the key technologies of temperature field measurement based on thermal infrared imager [D]. Beijing: China University of Chinese Academy of Sciences, 2013. (in Chinese)

[10] Xu Wei, Liu Li. Design and application of quantificational IR drone [J]. ***Electro-Optic Technology Application***, 2004, 19 (3): 21-24. (in Chinese)

[11] Lu Hengjian. The research of field infrared target temperature control technology [D]. Xi′ an: Xi′ an Technological University, 2014. (in Chinese)

[12] Joon Hwang. Optimal design and manufacturing of infrared surveillance camera mirror [C]//2010 5th IEEE International Conference on Nano/Micro Engineered and Molecular Systems(MEMS) 2010: 869-871.

[13] Cremer Frank. Processing of polarimetric infrared images for landmine detection [C]//2nd International Workshop on Advanced Ground Penetrating Radar, 2003: 216-221.

[14] Li Haoguan, Zhu Linghao. The comprehensive utilization of coal tar pitch [J]. ***Chemial Technology Market***, 2000, 8: 8-10. (in Chinese)

[15] Liu Kai. Study on asphalt pavement temperature field distribution pattern [D]. Xi′an: China Chang′an University, 2010. (in Chinese)