

EXPERIMENT TO EVALUATE THE EFFECTIVENESS OF THERMAL REFLECTIVE COATING APPLIED TO CONSTRUCTIONS

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Abstract

Constructions are usually made of materials like reinforced concrete and steel. In hot weather conditions, the reflected thermal radiance in the daytime and the emitted thermal radiance of human activities inside the structure are significantly higher than in the background. Thanks to the temperature difference between them, thermal imaging systems can easily detect or recognize the target. In order to reduce the thermal contrast, it is vital to research and apply the specific coating that can be used to cover the construction and the outside door. On the other hand, there is yet to be a method to evaluate the effectiveness of thermal reflective coating for constructions and mobile targets in Vietnam. Hence, the article has focused on performing the experimental measurement of the thermal difference between two coating materials. The result will also be applied to evaluate and select the effective thermal paint for the protected system.

Keywords: Thermal imaging; thermal contrast; thermal difference.

1. Introduction

The effectiveness of concealment can be defined as the detection, recognition, and identification range value that adapts to the commander's requirements. In order to archive it, the contrast between the structures and the background has to be reduced as much as possible. In addition, both permanent constructions and temporary structures have essential roles on the battlefield. To avoid detection by thermal reconnaissance equipment, constructions have to be applied to thermal concealment systems, such as coating and thermal concealment nets. In the targeting task performance (TTP) model, the target acquisition performance (detection, recognition, and identification) highly depends on the thermal contrast [1, 2]. To deal with it, thermal painting is one of the most effective ways can be developed.

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On the battle fields, the solar heating and the thermal resources from battle and living activity always affect the structures. Because of thermal coefficients, emissivity differences, and the size of structures, the thermal contrast between constructions and terrain is significant and so hard to balance. In most cases, it will become a clue for opponents to detect. To avoid it, it is necessary to develop and apply a special coating for construction to reduce the thermal contrast.

The article aims to develop a method to experiment and evaluate the thermal difference and thermal contrast between the target and environment. The result will be applied to set up a new method and procedure to test the thermal coating not only for buildings but also for other military objects.

2. Theoretical basis and experimental method

2.1. Characteristics of thermal imaging system

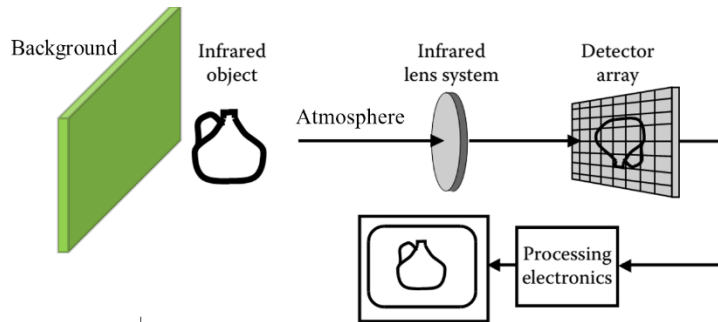


Fig. 1. Schematic of thermal imaging system.

The thermal imaging system (TIS) is the chain of subsystems (Fig. 1) that influence the output of the thermal images. Each system applies several transformations of the input image and affects the quality of the output image.

TIS is the system that collects the thermal radiation of the scene and transfers it into an electrical signal. Planck's law describes the spectral radiant exitance of a blackbody. The scene radiation, including background, target and atmosphere components, propagates through the atmosphere onto the detector of TIS. Depending on the atmospheric condition, the radiation can be absorbed, scattered and reflected by atmospheric constituents. Together, these phenomena degrade and add thermal noise to the thermal image. To simulate correctly the thermal camera, it is necessary to evaluate the characteristics of all subsystems.

Two significant characteristics of TIS are geometrical and thermal resolution. The geometric resolution of TIS is adequately characterized by its modulation transfer function (MTF). Blurring effects due to the filtering action of TIS components are

incorporated into the system via the cascaded MTF approach. The total system transfer function is the product of the component transfer functions [3, 4].

$$H_{sys} = H_{atm} \cdot H_{opt} \cdot H_{det} \cdot H_{elec} \cdot H_{disp} \cdot H_{eye} \quad (1)$$

where H_{sys} is the total MTF of system; H_{atm} is the atmospheric MTF; H_{opt} is the optical MTF; H_{det} is the detector MTF; H_{elec} is the electronic MTF; H_{disp} is the display MTF and H_{eye} is the human eye MTF.

The temperature sensitivity is characterized by noise equivalent temperature difference (NETD). NETD provides information about the noise that affects the thermal imager and limits the smallest temperature difference detectable by TIS. A parameter named fill factor is used in the focal plane array of the thermal imager. Thus, NETD is calculated by the following function [5]:

$$NETD = \frac{2\sqrt{\pi} \cdot (F)^2}{\sqrt{A_d} \cdot \tau_0 \cdot \tau_a \cdot D_p^* \cdot \int_{\lambda_1}^{\lambda_2} \frac{\partial M_{e,\lambda}}{\partial T} \frac{D^*(\lambda)}{D_p^*} d\lambda} \cdot \sqrt{F_R \cdot f_{factor}} \quad (2)$$

where F is the f -number of lens, A_d is the area of each detector's element, (cm²); τ_0 is the transmission of optical system; τ_a is the atmospheric transmission; $D^*(\lambda)$ is the spectral specific detectivity, (cm.Hz^{0.5}.W⁻¹); D_p^* is the peak spectral specific detectivity, (cm.Hz^{0.5}.W⁻¹); $M_{e,\lambda}$ is the spectral exitance, defined by Plank function; F_R is the frame rate; f_{factor} is the fill factor ratio and (λ_1, λ_2) is the spectral range of system.

2.2. Radiance calculation

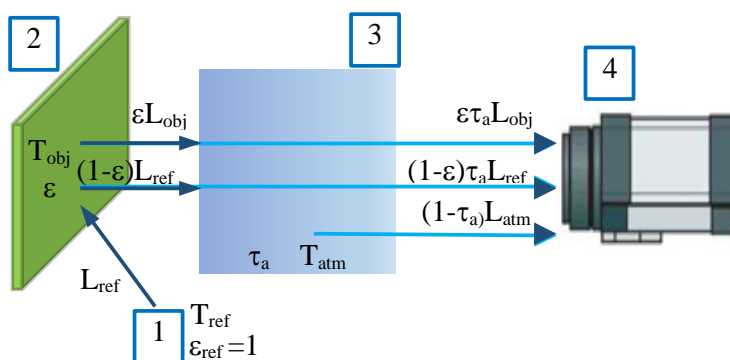


Fig. 2. A schematic of the general thermographic measurement
1 - Surroundings; 2 - Target; 3 - Atmosphere; 4 - Camera [6].

In basic terms, radiance detected by an IR camera is a combination of a target radiance emission, a target-reflected radiance, and an atmospheric radiance as measured through the detector's spectral response. The total received radiance on the detector has

three components (Fig. 2) and is calculated by using (3) [6, 7]:

$$L_{det} = \varepsilon \cdot \tau_a \cdot L_{obj} + (1 - \varepsilon) \cdot \tau_a \cdot L_{ref} + (1 - \tau_a) L_{atm} \quad (3)$$

where L_{obj} is emitted radiance of the target; L_{ref} is reflected radiance of ambient surroundings; L_{atm} is emitted radiance of the atmosphere.

To calculate in-band radiance, an integration function can be derived that incorporates with these terms. The total in-band radiance L_{det} is given:

$$L_{det} = \int_{\lambda_1}^{\lambda_2} \tau_0 \{ \varepsilon \cdot \tau_a \cdot L_e(\lambda, T_t) + (1 - \varepsilon) \cdot \tau_a \cdot L_e(\lambda, T_r) + (1 - \tau_a) \cdot L_e(\lambda, T_a) \cdot S(\lambda) \} \cdot d\lambda \quad (4)$$

In this formula, ε is the emissivity of target; $L_e(\lambda, T_t)$ is the target spectral radiance; $L_e(\lambda, T_r)$ is the spectral radiance of surroundings; $L_e(\lambda, T_a)$ is the path spectral radiance and $S(\lambda)$ is the spectral response of detector. $L_e(\lambda, T_a)$ and τ_a are generated by the modelling program MODTRAN. Based on Stephan-Boltzman law and total in-band radiance L_{det} , the estimated temperature of target also can be predicted.

2.3. Temperature difference

Temperature difference can be defined in various ways depending on the application. It is simply the difference in sensor output between the target and background temperature:

$$\Delta T = T_t - T_b \quad (5)$$

where T_t is the mean target temperature, T_b is the mean background temperature.

This term of temperature difference is used in the TTP model that predicts probabilities of detection, recognition, and identification of target. Although seemingly reasonable, this definition ignores temperature variances in both the target and the background. To take the temperature variation across a target into account, the temperature difference can be defined with the new method [7, 8]:

$$\Delta T = \sqrt{(T_t - T_b)^2 + \sigma_t^2} \quad (6)$$

where σ_t is the standard deviation of target's temperature.

Besides, the use of temperature difference, the thermal contrast is normalized to be dimensionless and has a value between 0 and 1 by definition:

$$C = \frac{T_t - T_b}{T_t + T_b} \quad (7)$$

The temperature difference is only calculated and measured by definition (5) in the article. However, the theoretical method should be used to simulate and evaluate with a

physical model. Another method is to perform experiments to evaluate the difference in the real environment.

3. Experimental performance

3.1. Measuring equipment

Field experiments have been conducted with thermal cameras such as the Moskito TI, the thermometer Extech VIR50, the thermometer Beurer HM16, and steel models covered by normal paint and INTERMAT coating concealment paint (Fig. 3).

HT-9815 is a basic thermo hygrometer that measures temperature indoors.



a) Camera Moskito TI b) Thermo Extech VIR50 c) Beurer HM16 d) Thermo Model HT-9815

Fig. 3. Measuring devices.

3.2. Experimental processing and evaluating thermal difference

3.2.1. Concealment paint samples

To experiment, two stainless steel samples have been produced. The samples' dimensions are $70 \times 70 \times 50$ cm. They were covered with the same material. There are two convection holes (4×20 cm) on the wall to ensure the air can convect between inside and outside the sample.

The experiment used 02 paint samples in where the sample 1 was covered with the concealment painting INTERMAT [9] when the sample 2 was painted with normal spray colour painting ATM.

3.2.2. Measure procedure

The procedure to receive the samples' temperature and samples' thermal images has been done by following the steps below:

Step 1. Set up the devices

A handheld temperature measuring device (Model HT-9815) was used to measure the air temperature inside the samples. Put the receiver of the thermal device into the

model through the convection hole. Avoid contact with the receiver with the surface of the sample.

Place the thermometer Beurer HM16 to measure the ambient temperature. The thermometer is placed on the brick floor between the two samples.

Place the thermometer Beurer HM16 to measure the ambient temperature. The thermometer is placed on the brick floor, located between the two samples.

Place the thermal camera Moskito TI in front of the samples at a distance of 5 m to take the thermal images of the model. The thermal camera can be used to get thermal images and compare the differences between the two models.

Use the thermometer Extech VIR50 to measure the surface temperature of the samples directly.

Step 2. Measuring surface temperature of samples

Use HT-9815 to measure internal temperature and Beurer HM16 to measure ambient temperature.

Take the thermal picture of samples with the thermal camera Moskito TI.

Use Thermo Extech VIR50 to measure surface temperature.

Step 3. Record the data and evaluate the temperature difference

The test was conducted from 9.8 to 17.8 and the result will be shown in the table 1.

3.3. Experimental results

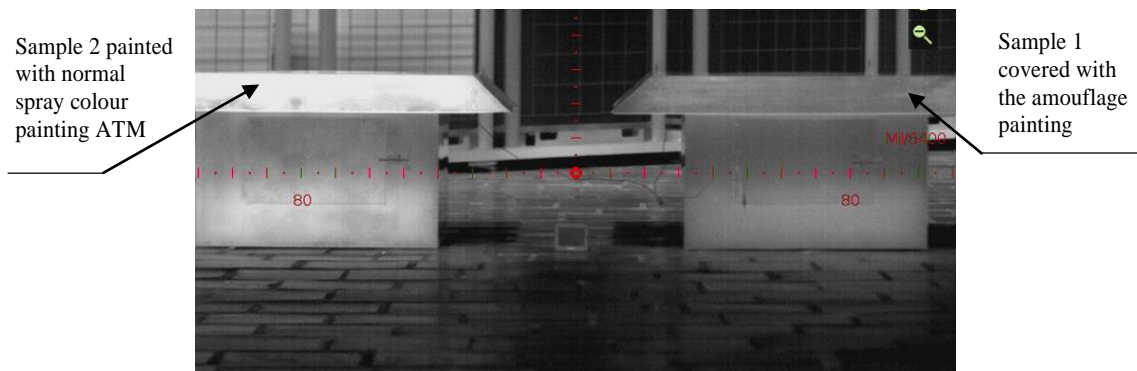


Fig. 4. The thermal images of two samples.

The left of the above picture shows the thermal imaging of sample 2. On the other hand, the right also illustrates the thermal image of sample 1. It is evident that the temperature difference between the two samples is significant. The details of the results

can be measured precisely by a thermometer, as shown in the table below.

Table 1. Experiment results

Date	Time	Ambient temp.	Sample 1 Surface temp.	Sample 2 Surface temp.	ΔT	Sample 1 Inside temp.	Sample 2 Surface temp.	ΔT
9-Aug	9	32	26.2	31.7	-5.5	30.7	31.7	-1.0
9-Aug	10	41.2	43.4	60.4	-17	39	39.5	-0.5
9-Aug	11	41.8	46.8	58.6	-11.8	41.3	41.5	-0.2
9-Aug	12	45.8	52	62.6	-10.6	43.6	42.9	0.7
9-Aug	13	47.1	53.5	65.2	-11.7	46.2	45.5	0.7
9-Aug	14	48	49.3	56.2	-6.9	48.8	50.1	-1.3
9-Aug	15	41.3	42.1	44	-1.9	43.9	44.7	-0.8
9-Aug	16	37.6	37.2	39.1	-1.9	40.3	40.4	-0.1
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16-Aug	9	36.3	43	47.3	-4.3	36.7	37.7	-1.0
16-Aug	10	35.8	41.9	46.4	-4.5	36.8	37.9	-1.1
16-Aug	11	39.3	61.4	71.5	-10.1	44.4	45.7	-1.3
16-Aug	12	38.5	58.7	67.3	-8.6	42.4	43.8	-1.4
16-Aug	13	42.9	60	64.1	-4.1	41.2	39.9	1.3
16-Aug	14	41.7	47.7	55.2	-7.5	39.1	39.4	-0.3
16-Aug	15	33.7	33.8	34.6	-0.8	31.2	32.9	-1.7
16-Aug	16	31.6	31.1	31.7	-0.6	30.6	30.8	-0.2

3.4. Data analysis

Analyze the data by using statistics and plot the data; the results have been shown in Fig. 5 - Fig. 10.

Using statistical analysis, the temperature difference between the two samples is shown in the table 2.

Table 2. Statistical results

	Surface temperature difference	Inside temperature difference
Mean	-5.40182	-0.50714
Standard Error	0.490698	0.090663
Median	-5	-0.5
Mode	-10.6	-0.5

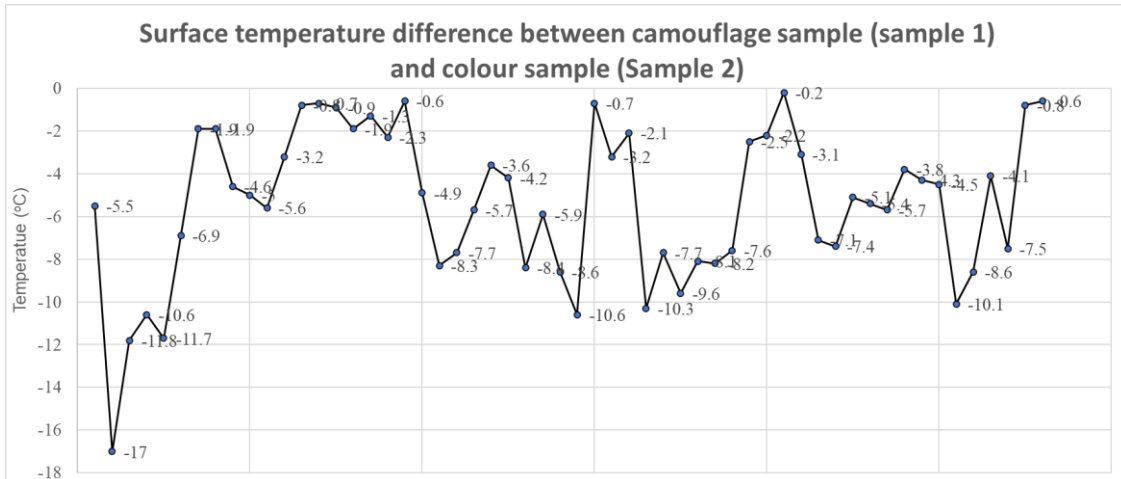


Fig. 5. Surface temperature difference between concealment sample (Sample1) and coloured sample (Sample 2).

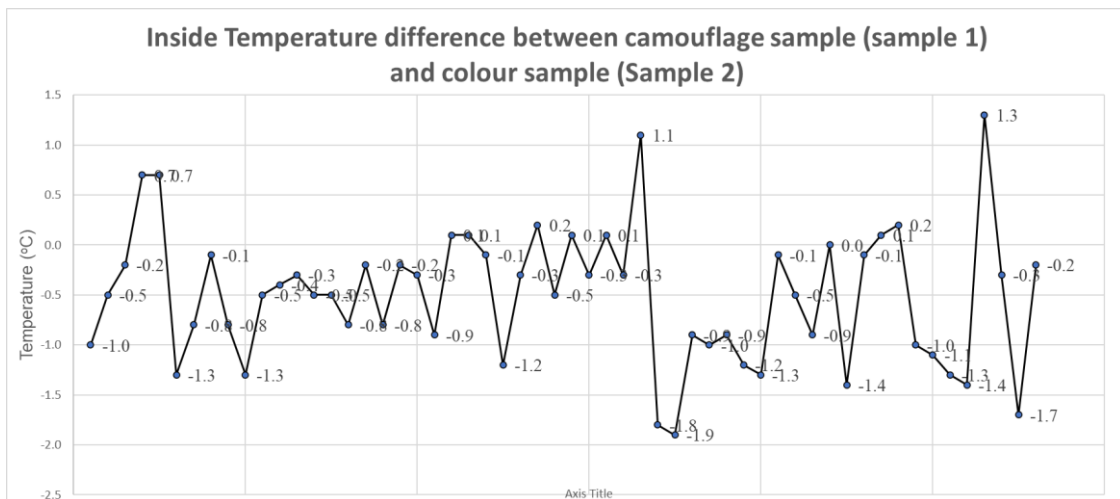


Fig. 6. Inside temperature difference between concealment sample (Sample 1) and colour sample (Sample 2).

In addition, the thermal contrast has also been analyzed to evaluate the effectiveness of thermal reduction. In the test performed on August 9th at 11 a.m., the thermal contrast of two areas (the roof and the body) of two samples was calculated based on the thermal

images. To solve the problems, the band of the image first is extracted and transformed into a gray image. Then the thermal contrast will be calculated and displayed in Fig. 8 and Fig. 10.

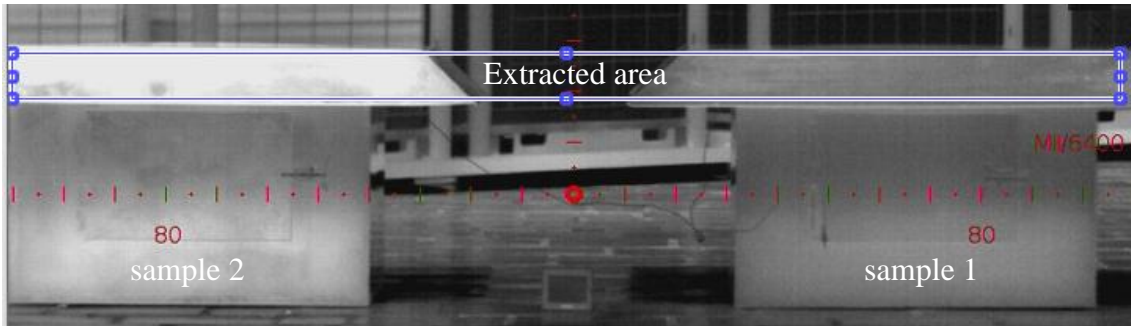


Fig. 7. The thermal image of two samples's roof and environment.

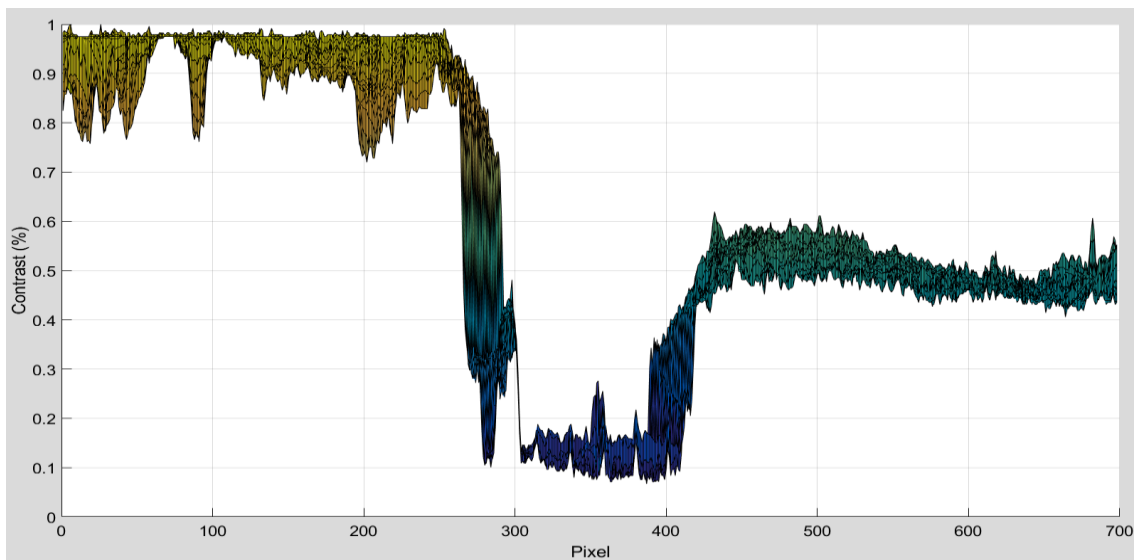


Fig. 8. The thermal contrast between two samples's roof and environment.

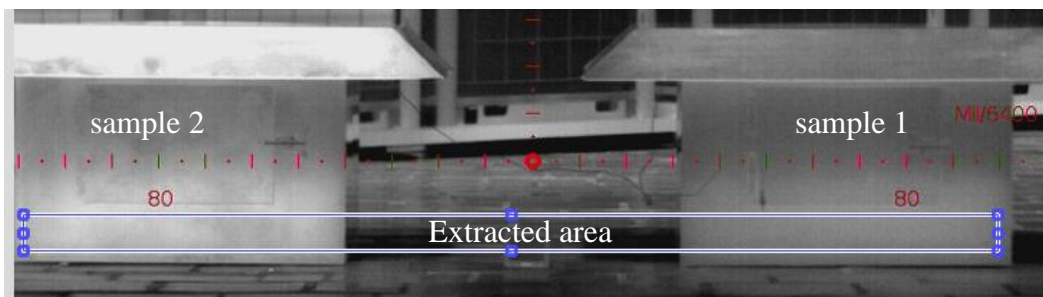


Fig. 9. The thermal image of two samples's roof and environment.

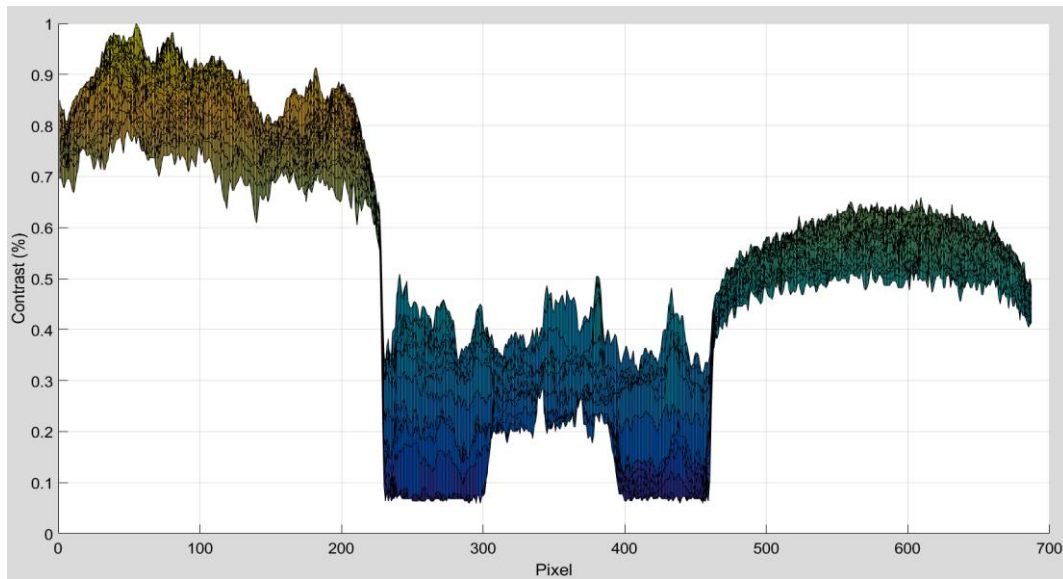


Fig. 10. The thermal contrast between two samples's body and environment.

3.5. Commendation

The experiments and analyses showed that the average temperature difference between concealment paint and non-concealment paint is significant. In the Vietnamese autumn climate, it is approximately 5 degrees Celsius. Moreover, the thermal contrast between the concealment sample and the color sample is about 30 - 50%. The experiment results show that thermal concealment can effectively reduce the surface target's temperature by 5 degrees. Hence, based on the recommendation of NATO standards, the effectiveness of concealment paints is acceptable and can be considered applied in Vietnamese weather conditions. The thermal coating can also be considered for construction.

4. Conclusion

Detecting constructions by using thermal cameras on modern battle fields is one of the most pressing current concerns. Management, reduction, and maintenance of the thermal balance between the construction and terrain are the keys to solving the problem. Hence, evaluating the difference between the targets and background is essential in the thermal concealment field.

In the article, the research focuses on establishing an experimental procedure to evaluate temperature differences. The results can be used to assess the effectiveness of thermal concealment coatings in construction. The test was conducted on two samples,

one coated with thermal concealment painting and the other coated only with normal color painting. The final experiment shows that the thermal paint of INTERMAT effectively reduces the thermal signal in daytime conditions. The thermal temperature can reduce by about 5 degrees, and the thermal contrast can reduce by 30 - 50% compared with normal color painting. However, because of a lack of testing equipment and budget, the test was only conducted to evaluate the thermal effect of solar energy. It is necessary to use and equip the scientific thermal camera that is able to get thermal radiance images. It is also recommended that the experiments in nighttime conditions also be tested, and the experiments on real constructions should be performed with the support of UAVs and thermal cameras.

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THÍ NGHIỆM ĐÁNH GIÁ HIỆU QUẢ CỦA CÁC LỚP PHỦ PHẢN XẠ NHIỆT ÁP DỤNG CHO CÔNG TRÌNH

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Tóm tắt: Các công trình thường được làm bằng vật liệu như bê tông cốt thép và thép. Trong điều kiện thời tiết nóng, bức xạ nhiệt phản xạ vào ban ngày và bức xạ nhiệt phát ra từ các hoạt động của con người bên trong công trình thường cao hơn đáng kể so với phong nền. Do sự chênh lệch nhiệt độ này, hệ thống ảnh nhiệt có thể dễ dàng phát hiện hoặc nhận dạng mục tiêu. Để giảm độ tương phản giữa chúng, điều quan trọng là phải nghiên cứu và áp dụng các lớp sơn phủ che giấu công trình và hệ thống cửa. Mặt khác, hiện tại vẫn chưa có phương pháp đánh giá hiệu quả của lớp phủ giảm bức xạ nhiệt cho công trình và mục tiêu di động tại Việt Nam. Vì vậy, bài báo này tập trung nghiên cứu và thực hiện đo giá trị thực nghiệm sự chênh lệch nhiệt giữa hai loại vật liệu sơn khác nhau. Kết quả cũng có thể được áp dụng để đánh giá và lựa chọn những loại sơn giảm tương phản nhiệt phù hợp với các công trình.

Từ khóa: *Ảnh nhiệt; tương phản nhiệt; độ chênh lệch nhiệt.*

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