This full-text paper was peer-reviewed at the direction of IEEE Instrumentation and Measurement Society prior to the acceptance and publication.

Thermochromic Temperature Measurement: Towards an Alternative to Thermal Cameras

Thomas Nussbacher
Institute of Visual Computing
Graz University of Technology
Graz, Austria
thomas.nussbacher@student.tugraz.at

Philipp Fleck
Institute of Visual Computing
Graz University of Technology
Graz, Austria
philipp.fleck@tugraz.at

Clemens Arth
Institute of Visual Computing
Graz University of Technology
Graz, Austria
clemens.arth@tugraz.at

2025 IEEE Sensors Applications Symposium (SAS) | 979-8-3315-1193-7/25/$31.00 ©2025 IEEE | DOI: 10.1109/SAS65169.2025.11105166

***Abstract*—This work presents a cheap alternative to using thermal cameras or other expensive temperature measurement devices to measure surface temperatures. We make use of color-changing pigment and a simple RGB webcam to get an estimated temperature value of a selected area in an image. We take a closer look at the properties of different thermochromic pigments and how they can be applied to different surfaces. Finally, we demonstrate how a calibration procedure is used to analyze the behavior of the pigment and form a connection between temperature and color, allowing us to estimate the current temperature.**

***Index Terms*—temperature measurement, thermochromism, camera, image processing**

I. Introduction

In a multitude of real-world applications, we need to measure surface temperatures for various reasons, such as to check machine heat or to check insulation of buildings. Infrared thermography offers a solution by using sensors to measure heat without contact, allowing for a precise and quick temperature assessment. This technology helps prevent overheating, energy loss, and unnecessary expenses by identifying temperature changes efficiently.

Infrared thermography devices include Infrared Thermometers, Pyrometers, and Thermal Infrared Sensors, with infrared thermal cameras being the most prominent. Unlike RGB cameras, thermal cameras work in the infrared spectrum to capture heat emitted, visualizing temperature differences with grayscale or false color. They can detect heat variations even in complete darkness. Infrared thermometers measure temperature at a single point or area, offering limited insight. In contrast, thermal cameras capture a broader scene, making them ideal for night vision, industrial inspections, and temperature monitoring.

Thermal cameras are expensive due to specialized technology and materials, unlike more affordable and mature RGB cameras. Despite technological advancements, thermal cameras remain pricier, with their complex heat-detecting sensors contributing to higher costs. This implies that scenarios that require the coverage of larger areas can only be dealt with by investing significant financial funds.

In this work, we propose a cheap alternative for temperature monitoring without thermal cameras. The presented **estimation system** involves thermochromic paint [1], [2], which is applied to surfaces. In this way, we are able to get visual feedback about the approximate temperature. Following a calibration process, where the properties of the paint are analyzed, a mere RGB camera becomes sufficient to derive an accurate estimation of the current temperature on the target surface.

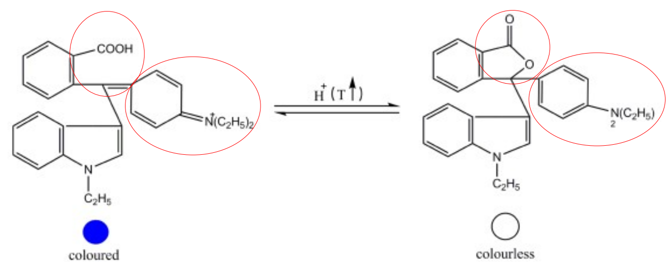

Fig. 1. Illustration of how a blue thermochromic pigment changes its molecular structure when heated up, transitioning from blue to colorless. Since this transformation is reversible, the compound changes back to its original structure and color when cooled down. The red cycles show the parts of the molecule that are affected by the temperature change. Image taken from [1].

With this estimation system, it is also possible to measure surface temperatures in scenarios where thermal cameras cannot be easily deployed. An example would be when the target surface is placed behind glass, as is common in manufacturing environments. Regular quartz glass blocks infrared rays, and special translucent germanium glass is very expensive. Since RGB camera sensors have no difficulties with such materials our proposed method can elegantly work around this problem.

The remainder of this document is structured as follows. Sec. II discusses thermochromism and Sec. III is dedicated to related work. In Sec. IV characteristics of the pigments are described, while experimental results are discussed in Sec. V. Concluding remarks are finally given in Sec. VI.

II. Thermochromism

Chromism is a fascinating property of certain materials, which refers to their ability to undergo a change in color in response to specific external stimuli [3]. This phenomenon adds a dynamic dimension to these materials, making them responsive to factors such as light (photochromism), temperature (thermochromism), pH (holochromism), or other environmental conditions. The ability of a material to transition between different colors is found in applications for creating appealing and interactive entertainment products, but it also serves a practical purpose in various other fields. In the realm of chromic materials, thermochromism stands out as an interesting subset.

Thermochromism is a chemical phenomenon, most commonly in the realm of organic chemistry. The term refers to the property of certain compounds to change in color when exposed to alterations in temperature. The color change occurs in a reversible manner and is limited to a specific temperature range. This property was first formally recognized in the late 1920s, with simultaneous reports [4] on the thermochromic behavior of di-naphthospiran, a colorless compound that transformed into a blue-violet melt upon heating and reverted to its original state upon cooling.

The term thermochromism includes a broad spectrum of compounds that undergo noticeable and reversible color changes within specific temperature ranges. The mechanisms responsible for such phenomena are diverse and can be attributed to factors such as crystal structures or molecular transformations such as ring opening and the formation of free radicals. Fig. 1 shows an illustration of this transformation.

Thermochromic materials include liquid crystals and leuco-dye pigments. Liquid crystals have both liquid and solid properties, and their color changes as a result of shifts in molecular alignment with temperature changes. Leuco-dye pigments switch between colored and colorless states through a reversible chemical reaction triggered by temperature variations. The color range of thermochromic liquid crystals is often limited to specific wavelengths associated with their molecular structure, whereas leuco dye pigments can exhibit a broader range of colors, depending on the specific chemical composition of the dye. Both thermochromic liquid crystals and thermochromic leuco dye pigments offer unique advantages and are chosen based on the specific requirements of the application.

The **activation temperature** T_A of the thermochromic pigments refers to the specific temperature at which these pigments undergo their color change. The activation temperature can vary depending on the specific formulation of the thermochromic compound and its intended application. For most pigments, the transformation starts already before the respective activation temperature is reached. After this temperature threshold, the transformation is guaranteed to be complete. In this temperature range, from the start of the transformation to the completion of the full transformation, we are able to determine the exact surface temperature using our estimation system. Depending on the thermochromic compound and its formulation, this transition phase can occur in temperature ranges of 10 °C to 70 °C. However, for the majority of conventional pigments this range lies at the lower end.

III. Related Work

In the following, we examine several real-world applications of these dynamic compounds. Furthermore, we discuss works that investigate the properties of these colors under specific circumstances. Analyzing the chemical and optical aspects of thermochromic pigments in diverse conditions helps better predict their behavior and applicability. Finally, we explore an initial approach that utilizes thermochromism for temperature measurement.

A. Real world applications

Perez *et al.* [5] examine a reversible thermochromic mortar for use as an external building coating. Based on white Portland cement with thermochromic pigments, the mortar shows increased reflectance by up to 50% in the visible range. The pigments enable a color change from dark to light, leading to a 19% reduction in solar absorbance above the transition temperature, improving energy efficiency by reducing surface heating.

Civan *et al.* [6] developed coatings using a sol-gel spraying method with MTEOS, TEOS, and thermochromic pigments that switch between absorbing and reflecting energy. Their aim is to reduce heating and cooling loads in buildings. Heat-treated and tested with various analyses, the coatings show good temperature sensitivity with reversible phase transitions at 36.3 °C and 27.5 °C. The authors state these coatings can aid in urban microclimate management and energy saving, suitable for application on windows of buildings or cars.

Thermochromic ink is used in smart packaging [2], which changes appearance to indicate improper storage conditions for temperature-sensitive products like foods, aiding both sellers and consumers in handling them correctly.

Peoples *et al.* [7] discusses Thermochromic variable Emittance Coatings (VECs) ideal for passive thermal management in spacecraft. Lanthanum Strontium Manganite (LSM) with tunable solar absorption and infrared emittance is promising. LSM's transition temperature, depending on the Lanthanum-to-Strontium ratio, can be represented as $La_{1-x}Sr_xMnO3$. With x=0.2, we obtain $La_{0.8}Sr_{0.2}MnO3$. $La_{0.8}Sr_{0.2}MnO3$ shows an IR emittance increase from 0.5 below -3 °C to 0.8 at 67 °C over a 70-degree range, making LSM suitable for spacecraft applications.

B. Property Studies

Kulcar *et al.* [8] studied thermochromatic inks, focusing on color transitions with temperature changes. They used four UV-curable inks: UV TCX R-31 and UV TCX B-31 from Coates Screen Inks GmbH, and SicpaRed-33 and SicpaBlue-45 from Sicpa. The inks, containing leuco dye thermochromic pigments with various activation temperatures, were mixed and applied to OBA-free gloss coated paper, then cured with UV light. These samples underwent heating and cooling cycles, facilitated by a thermostatic circulator, to monitor color changes using the CIELab space and CIEDE2000 formula [9]. Kulcar *et al.* noted a hysteresis effect, where color differed depending on whether samples were cooling or heating, as shown in Fig. 2. For predicting temperatures from color, it's crucial to focus on the cooling transition, as different colors can affect accuracy based on prior heat. We'll address this limitation and explore software solutions later.

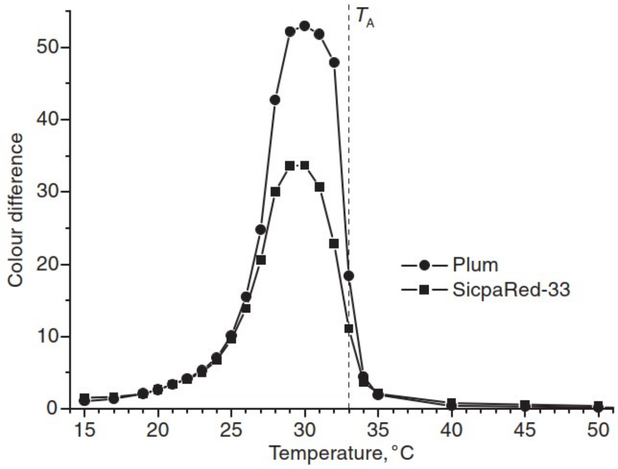

Fig. 2. Color difference between heating up and cooling down of two conventional thermochromic inks. Although they have the same activation temperature T_A, they display unequal colors when comparing a pre-heated and pre-cooled state. This difference in appearance has its peak slightly below T_A, during the transition phase. Image taken from [8].

Kantola *et al*. [10] studied the color stability of thermochromic pigment in maxillofacial silicone elastomer. Silicone was divided into three groups: two containing a share of 0.2%, respectively 0.6% thermochromic pigment, and a control group without pigment. Specimens were molded and polymerized for 2 hours at 90 °C. After 20 days in dark storage at room temperature, baseline color measurements were taken. Specimens were then exposed to UVA radiation for 6 hours daily, with color measured using a Konica Minolta spectrophotometer in the CIELAB color space. UV irradiation had a significant effect on the color values of all specimens already right after the first exposure. As a result, not all substances are suitable for being used in combination with thermochromic pigments.

Ibrahim [11] applied leuco dye and cholesteric liquid crystals on textiles using printing and extrusion. The color strength of thermochromic pigments is less in comparison to that of other commercially available pigments. This is because of the lower amount of dye that is present in the final formulation. Therefore, the ratio of thermochromic pigments was adjusted to avoid pale shades. One outcome of this work is the need for a binder, *i.e.* a carrier emulsion, to enable painting.

C. Temperature Measurement and Color Calibration

Toriyama *et al*. [12] introduce a temperature measurement method using thermochromic liquid crystals (TLC). The hardware included an optical receiver, a halogen lamp with an infrared cut-off filter, and a water jacket. A cholesteric-type TLC sheet and type T thermocouples were placed on the water jacket's surface, which was constructed from a 20 mm thick aluminum plate. The temperature of the TLC sheet varied from 20 °C to 60 °C in increments of 1 °C, exceeding the range of color change of the TLC sheet (32-42 °C). A scheme of the experimental setup is illustrated in Fig. 3.

The results show that the peak in spectrum intensity shifts with temperature, enabling precise temperature determination.

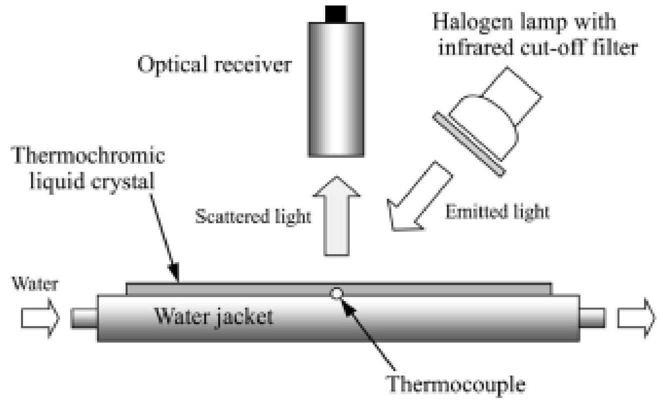

Fig. 3. Scheme of the experimental setup to measure scattered light's spectrum intensity. A halogen lamp is used as a light source. On optical receiver allows to observe the scattered light from the thermochromic layer on top of the water jacket. Image taken from [12].

Experiments using a monochrome camera show promising results, with a measurable temperature range (27–47 °C) surpassing conventional TLC methods (32–42 °C). This experiment proves that TLCs can be used for temperature measurement.

In the work of Haeghen *et al*. [13], a method is described for calibrating an imaging system by transforming an unknown color space to the well-known sRGB color space. When working with commonly used color spaces like RGB or HSV, one has to keep in mind that the color space varies between imaging systems. For this reason, the authors introduce a method for calibrating an imaging system to transform to a device-independent color space. The calibration procedure involves a series of steps, including adjusting camera parameters, maximizing the dynamic range and achieving gray balance with the construction of a lookup-table. Afterwards, the images can be transformed to the sRGB color space.

IV. Pigment Characteristics and Application

The insights from related work provide a good baseline on how to handle the pigments and what behavior can be expected. Due to the wide range of different thermochromic pigments and different approaches to the individual works, we first need to study the behavior of each pigment individually and investigate how to apply the pigments to different surfaces.

A. Pigments

It is important to distinguish between thermochromic liquid crystals and leuco dye pigments. We focus only on leuco dye pigments due to their accessibility and suitability for creating a cost-effective large-area temperature measurement solution. In the following we give a quick overview of several thermochromic pigments, with details in Table I and an illustration of the respective color change in Fig. 4.

- **Green to Orange Pigment:** manufactured by "FILFEEL"[1], the pigment transitions from green to a light orange color. With an activation temperature of only 31 °C, it is possible to manipulate its color only using ones body temperature.

[1] FILFEEL pigment on Amazon

Type/ Name	Main Color	Secondary Color	Activation Temp. T_A	Cost
Black Pig.	Black	Colorless	50 °C	∼1€ / 10g
Black Pig.	Black	Colorless	65 °C	∼1€ / 10g
Black Pig.	Black	Colorless	70 °C	∼1€ / 10g
Green Pig.	Green	Orange	31 °C	∼8€ / 10g
UR02	Light Blue	Light Purple	25-35 °C	2,50€ / 7ml
UR03	Dark Blue	Light Purple	25-35 °C	2,50€ / 7ml
UR05	Purple	Light Purple	25-35 °C	2,50€ / 7ml
UR06	Dark Orange	Yellow	25-35 °C	2,50€ / 7ml
UR011	Gray	Light Pink	25-35 °C	2,50€ / 7ml
UR012	Dark Cyan	Light Cyan	25-35 °C	2,50€ / 7ml

TABLE I
AN OVERVIEW OF ALL PIGMENTS (PIG.) AND COLORS THAT WERE PART OF THE EXPERIMENTS. UR02-UR12 ARE THE NAMES OF THE COLORS FROM THE THERMOCHROMIC NAIL GEL POLISH SET.

- **Black to Transparent Pigment:** available from different Chinese companies[2], the pigments transition from black to colorless upon heating at activation temperatures of 50 °C, 65 °C and 70 °C.
- **Thermochromic Nail Gel Polish:** produced by "UR SUGAR"[3] these vials contain a UV-sensitive nail gel polish with built-in thermochromic features. Upon reaching the activation temperature of approximately 30 °C, each gel undergoes a transition from a dark tone to a lighter tone of their respective color, *i.e.* shades of gray, purple, pink, brown, olive-green, and cyan.

B. Binders And Suitable Surfaces

In order to apply pigments to different surfaces, a suitable binder is required. Color lacquer shows good mixing capabilities, is resistant to environmental influences, is inexpensive, and can be used on almost all types of surfaces. These include textile fabric, plastic, wood, metal, and many more.

For testing purposes, PET plastic cups have been proven to be suitable because of their ability to store liquids and the fast assimilation of surface temperature to the temperature of the contained liquid. Heated water can be used to investigate the color changing behavior of the pigments. An extensive discussion of different emulsions is beyond the scope of this paper; however, the interested reader is referred to the work of Nussbacher [14] for more details.

V. EXPERIMENTS

On the basis of the set of different pigments, the goal of our experiments is to investigate the behavior of transitioning from one color to the other. In more detail, we want to defer a characteristic, which enables us to map a color to an actual surface temperature, such that we can essentially *measure temperature by color*.

A. Hardware Setup

Two cameras are placed side by side, both facing the colored surface. One RGB camera, a Logitech C920 Pro HD webcam, is used to capture the color change, and one thermal camera, a Seek Thermal S314SPX[4], is used to measure the actual real

[2]Pigment Manufacturing Companies, China
[3]Nail Gel Polish on Amazon
[4]Seek Thermal Sensor Datasheet

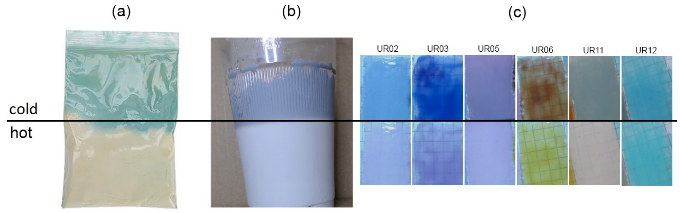

Fig. 4. The thermochromic colors before and after the color transition. The top half shows the colors in a cooled state, the bottom half in a heated state. (a) Green pigment. (b) Black pigment (50 °C) mixed with color lacquer. (c) Nail gel colors.

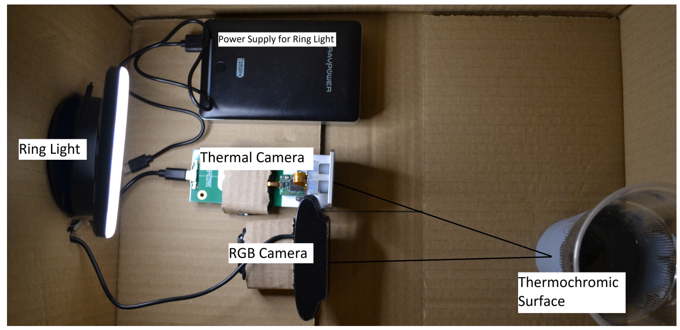

Fig. 5. The setup used for the experiments regarding temperature estimation. Two cameras facing a thermochromic surface and a ring light to ensure sufficient lighting conditions.

surface temperature. As a surface, we used a regular plastic cup, painted with a mixture of pigment and color lacquer. For consistent measurements, the whole setup is mounted inside a sealable box, using a white light as const. light source (Fig. 5).

B. Calibration

The goal of the calibration procedure is to map the color values measured by the RGB camera to the temperature values measured by the thermal camera. Before starting the calibration procedure, the cup is filled with water whose temperature is well above the activation temperature (*i.e.* T_A + 20 °C) of the pigment[5]. In contrast to the heating phase of materials, the repetitive cooling needs no special hardware or temperature-controlled environment, but can be done at room temperature.

Once the pigment is activated, temperature and color values are collected at a chosen sampling rate until the temperature value is well below the activation temperature of the respective pigment (*i.e.* T_A - 20 °C). The samples are acquired for an image location, the calibration point, that represents about the same physical location on the plastic cup surface. This location is chosen around the image center in advance within the thermal, respectively, RGB image (see Fig. 6)[6]. Due to consistent behavior through the experiments and for simplicity we used data from only a single run for the calibration process.

In order to reduce noise and arrive at more accurate measurements, multiple temperature values surrounding the

[5]For pigments with an activation temperature below room temperature, other regulation mechanisms must be used, such as a water jacket used for the experimental setup of Toriyama *et al.* [12].
[6]For simplicity we leave the geometric inter-modality calibration of the two cameras out as future work.

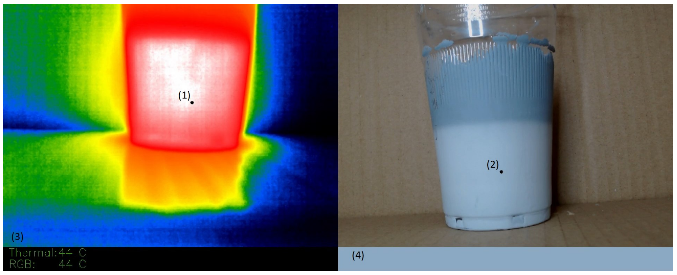

Fig. 6. Example frame of the estimation software output. For verification of the estimation accuracy, the thermal camera is used as comparison. The captured frames of the thermal camera and the RGB camera can be seen. (1) Measurement point for thermal camera. (2) Measurement point for RGB camera. (3) Comparison of the measured temperature from the thermal camera and the calculated/estimated temperature using the RGB camera. (4) Representation of the mean color at the selected area of the RGB image, used for the estimation.

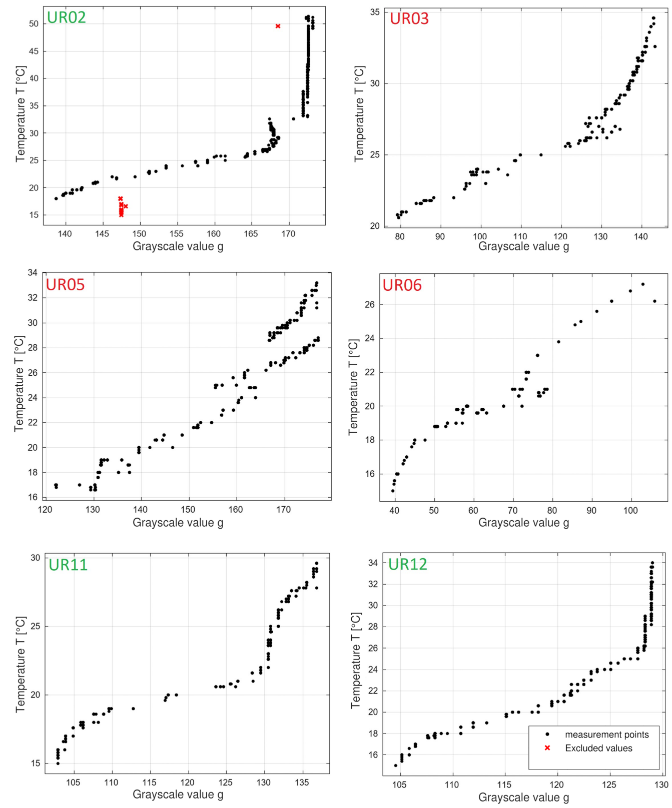

Fig. 7. The temperature-grayscale graphs for the thermochromic nail polish. Due to uneven thickness distribution the results vary. While UR03, UR05 and UR06 (red) seem to deliver unusable data, the remaining colors UR02, UR11 and UR12 (green) seem to be more promising candidates for an estimation.

calibration point are used to smooth out the results. Therefore, the mean temperature within a 49-neighbourhood (7x7 grid) around the calibration point is calculated. Similarly, the mean RGB values of the corresponding 49-neighborhood in the visible-light image are determined.

All samples collected during the period of time between the respective temperature limits are stored in a data file for later analysis.

C. Data Analysis

The calibration procedure yields temperature estimates and an additional feature vector derived from the RGB camera, *i.e.* the amounts of red, green and blue, brightness, etc. However, we primarily aim for a plausible mapping of temperatures to the corresponding grayscale values. Our focus is on the flat regions formed during the activation phases to avoid error prone readings.

The data collected for the nail gels are shown in Fig. 7. The results for all colors were quite different. During the tests, achieving an even distribution of the colors across a surface has turned out to be difficult. While UR02, UR11 and UR12 seem to be easier to paint, all other colors, UR03, UR05 and UR06 turned out to be very sensitive to thickness variations, creating significant color differences[7]. Therefore these colors were determined to be unsuitable for further investigations. Overall, the gels begin their color transition at about 15 °C and saturate at activation temperatures of 26-30 °C. This gives a temperature range of 11-15 °C, similar to black pigments. The best results were achieved with UR12.

In order to analyze the importance of external parameters, several calibration runs were performed using black-transparent pigments. In particular, the cool-down phases were recorded using single-frame samples and natural light, instead of the constant light source. The variation in grayscale values is clearly visible, indicating a considerable level of noise in the values delivered by the RGB camera sensor. In contrast, on the right of Fig. 8 recordings using a constant light source are shown, additionally averaging the measurements over multiple frames[8]. We use Matlab's Curve Fitting extension to quickly generate functions using the data points as input, to obtain a function $T[g]$ (*i.e.* temperature with respect to the grayscale value). An example of such a function created from a mixture of Gaussians can be found as blue curve in Fig. 8 respectively. Some points on the top right have been excluded (red cross), since in this area, the density of the data became unusable and would result in inaccurate estimation results. Here the resulting function $T[g]$ is already generated, shown as a blue line. In this example, the function representing the data is a sum of multiple Gaussian functions.

D. Validation

To analyze the accuracy of our estimation, we performed multiple iterations of cooling down the thermochromic surface until the lower saturation point was reached. During this process, the actual and estimated temperature is compared. The maximum deviation of the estimated temperature, *i.e.* the temperature derived from the grayscale temperature mapping, and the measured temperature, *i.e.* the measurement given by the thermal camera, was 2 °C (mean 1.09 °C, std.dev. 1.9 °C). Before and after the effective temperature range was reached, we successfully determined whether the temperature is above or below the defined upper and lower limit.

[7]This problem was present in all repeated operations.

[8]The data is recorded at a framerate of about 10Hz. We average about the frames captured in 2 seconds, *i.e.* 20 frames.

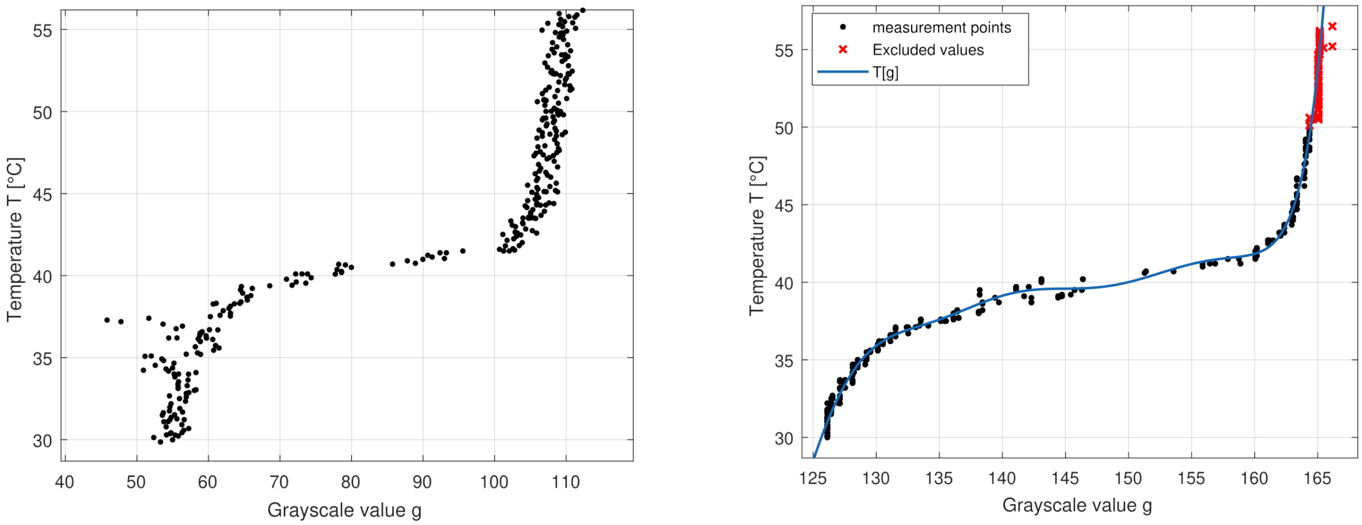

Fig. 8. Example data points from different calibrations iterations of the 50 °C black pigment. Each black dot represents one entry from the corresponding generated data file. Left: Before implementation of improvements. Right: After adding a constant light source and implementing frame averaging.

E. Discussion

Our experiments focused solely on the cool-down phase of dyes, due to the need of special hardware and temperature-controlled environments for controlled heating. Fig. 2 shows that the appearance of the color varies with the prior temperature states. Thus, using our method in the heat-up phase leads to inaccurate temperature estimates. To accurately detect when the temperature exceeds a threshold, ensure that calibration is performed during the heat-up phase. To achieve accurate bidirectional estimation, our system must create two temperature-color functions: one for heating up and one for cooling down. The appropriate curve then has to be chosen on the basis of an estimated temperature trend.

The calculable temperature range depends on the pigment properties. For black pigments, we achieved an effective range of about 10 °C. This range can be slightly extended, but accuracy decreases near saturation points. Due to small ranges, the system suits specific applications like binary detection. Surveilling surfaces covered with different pigments subject to different activation temperatures might enlarge the overall range. Our work shows the potential of these pigments.

VI. Conclusion

We have developed a method that allows us to estimate the temperature on surfaces that have been painted with thermochromic pigment. We investigated the color-changing behavior of thermochromic leuco dye pigments. Following a calibration procedure, we successfully demonstrated the ability of our estimation system to predict temperatures only using an RGB camera.

Acknowledgment

Funded by the European Union under Grant Agreement No. 101092861. Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the granting authority can be held responsible for them.

References

[1] J. Hu and X. Yu, "Reflectance spectra of thermochromic asphalt binder: characterization and optical mixing model," *Journal of materials in Civil Engineering*, vol. 28, no. 2, p. 04015121, 2016. 1

[2] E. Thamrin, E. Warsiki, Y. Bindar, and I. Kartika, "Thermochromic ink as a smart indicator on cold product packaging-review," in *IOP Conference Series: Earth and Environmental Science*, 2022. 1, 2

[3] M. Ferrara and M. Bengisu, *Materials that Change Color - Smart Materials Intelligent Design*, 11 2014. 1

[4] J. H. Day, "Thermochromism." *Chemical Reviews*, vol. 63, no. 1, pp. 65–80, 1963. 2

[5] G. Pérez, V. R. Allegro, M. Corroto, A. Pons, and A. Guerrero, "Smart reversible thermochromic mortar for improvement of energy efficiency in buildings," *Construction and Building Materials*, vol. 186, pp. 884–891, 2018. 2

[6] Civan, Lale and Kurama, Semra and Ayas, Erhan and Mutlu, Yasemin Çimen, "Control of temperature changes in daily life with thermochromic green pigments," *Materials Letters*, vol. 272, p. 127846, 2020. 2

[7] Peoples, Joseph and Taylor, Sydney and Massina, Christopher and Ruan, Xiulin, "Impact of thermochromic coatings on thermal management for human spacecraft applications," in *Thermal and Fluids Analysis Workshop*, 2021. 2

[8] R. Kulčar, M. Friškovec, M. K. Gunde, and N. Knešaurek, "Dynamic colorimetric properties of mixed thermochromic printing inks," *Coloration Technology*, vol. 127, no. 6, pp. 411–417, 2011. 2, 3

[9] G. Sharma, W. Wu, and E. N. Dalal, "The ciede2000 color-difference formula: Implem. notes, supplem. test data, and math. observations," *Color Research & Application*, vol. 30, no. 1, pp. 21–30, 2005. 2

[10] R. Kantola, L. V. Lassila, M. Tolvanen, and P. K. Valittu, "Color stability of thermochromic pigment in maxillofacial silicone," *The Journal of Advanced Prosthodontics*, vol. 5, no. 2, pp. 75–83, 2013. 3

[11] W. Ibrahim *et al.*, "An investigation into textile applications of thermochromic pigments," Ph.D. dissertation, Heriot-Watt Univ., 2012. [Online]. Available: https://core.ac.uk/download/pdf/77035382.pdf 3

[12] K. Toriyama, S. Tada, K. Ichimiya, S. Funatani, and Y. Tomita, "A new method of temperature measurement using thermochromic liquid crystals (extension of measurable range based on spectral intensity in the narrow-band wavelength)," *International Journal of Heat and Mass Transfer*, vol. 92, pp. 483–489, 2016. 3, 4

[13] Y. V. Haeghen, J. M. A. D. Naeyaert, I. Lemahieu, and W. Philips, "An imaging system with calibrated color image acquisition for use in dermatology," *IEEE transactions on medical imaging*, vol. 19, no. 7, pp. 722–730, 2000. 3

[14] T. Nussbacher, "Thermochromic Temperature Measurement: A cost-efficient alternative to thermal cameras," Bachelor's Thesis, Graz University of Technology, Inffeldgasse 16/2, A-8010 Graz, Austria, Feb. 2024. [Online]. Available: https://repository.tugraz.at/records/e6mnd-e8r18 4