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Preserved Relative Differences between Regions of Different Thermal Scans

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***Abstract*—Rheumatoid Arthritis patients have swelling and pain in joints of the hand. The regions where the patient feels pain also show increased body temperature. Thermal cameras can be used to detect the rise in temperature of the affected regions. To monitor the progression of Rheumatoid Arthritis, patients must visit the clinic regularly for scanning and examination. After scanning and evaluation, the dosage of the medicine is regulated accordingly. To monitor the disease progression over time, the correlation of the images between different visits must be established. It has been observed that the thermal measurements do not remain the same over time, even within a single scanning, when low-cost thermal cameras are used. In some situations, temperatures can vary as much as 2°C within the same scanning sequence. In this paper, it has been shown that although the absolute temperature varies over time, the relative difference between different regions remains similar. Results have been computed over four scanning sequences and are presented.**

***Keywords*—Relative thermal difference, rheumatoid arthritis, thermal imaging, thermal sensors.**

I. Introduction

ALL objects possessing temperature above absolute zero (equivalent to 0 Kelvin or -273.15°C) generate heat that is emitted as infrared radiation. The temperature of the object defines the intensity and the spectral distribution of the emitted radiation. This infrared radiation is detected using thermal cameras equipped with thermal sensors, creating a thermal map that defines the temperature distribution on the body. The process of capturing the thermal radiations and converting them into an image is called *Thermal Imaging* (TI). In literature, different terms are used for *Thermal Imaging* such as Thermal Infrared Imaging, Infrared Imaging, or Thermography [1]. Thermal imaging is a sensitive, non-invasive, non-radioactive and contact-less method for monitoring inflammatory diseases [2].

The earliest thermal cameras faced technical problems such as calibration, low detector sensitivity, and thermal drift to name a few [1], [3]. Some of the problems have been addressed by modern thermal cameras developed in the last twenty years by providing higher resolution and faster acquisition time. These improvements have led to a wide variety of thermal imaging applications in medical [4], [5] and industrial domains [6]. Sousa *et al.* [7] and Calin *et al.* [1] reviewed the applications of thermal imaging for medical diagnostics.

Thermal imaging finds usage in industrial applications [6] such as:

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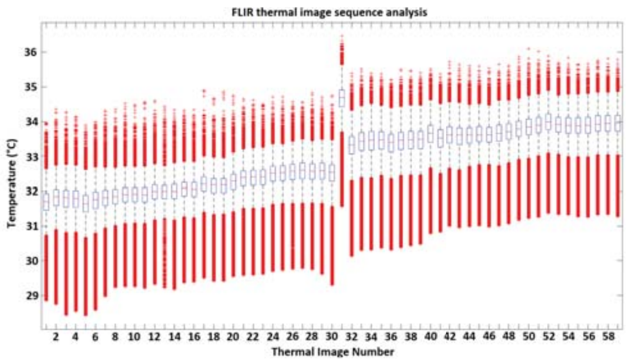


Fig. 1 Box plot of acquired thermal scans over time

- High voltage installations for example oxidation of high voltage switches, overheated connections, incorrectly secured connections, insulator defects
- Low voltage installations for high resistance connections, corroded connections, internal damage, internal circuit breaker faults, poor connections
- Mechanical installations for lubrication issues, misalignment, overheated motors, suspect rollers
- Overloaded pumps, overheated motor axles, hot bearings
- Pipework to detect leakage in pumps, pipes and valves, insulation breakdowns, pipe blockage
- Refractory and petrochemical installations
- Seeing through the flames
- Flare detection
- Detecting the level of liquid inside a tank
- Inspection of aeronautical material
- Mould inspection
- Checking temperature distribution in asphalt pavements
- Inspections in paper mills
- Finding hot spots in welding robots
- checking heating and ventilation systems

Since ancient times, the temperature of the human body has been used as an indicator of a disease. Rheumatoid Arthritis (RA) is an autoimmune disease that may affect flexible joints such as hand joints, wrist, feet, knee, shoulders, and other regions of the body [8]. It causes pain, stiffness, swelling and loss of function in the affected joints [9]. It can be diagnosed using several medical examinations and imaging scans such as X-ray, ultrasound, MRI, and Computed Tomography (CT) scans. However, X-ray and CT are harmful as they deliver harmful radiation to the body. CT angiography can deliver a 100 to 1000 times higher amount of radiation compared to a chest X-ray. Exposure to X-rays can cause DNA mutations

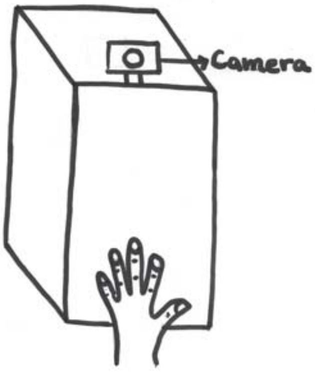
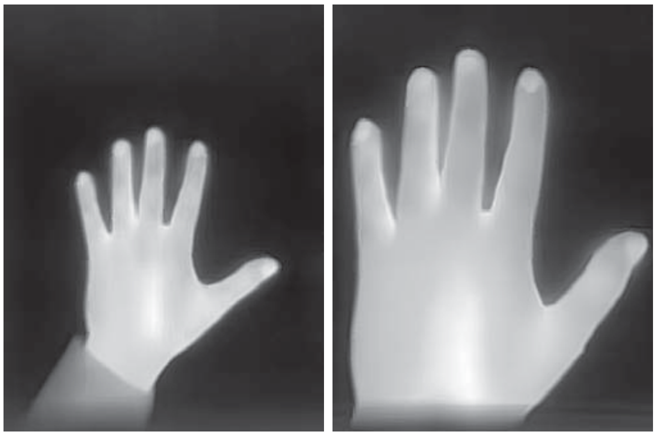


Fig. 2 Schematic diagram of thermal scan acquisition setup



(a) (b)

Fig. 3 Thermal scans

which can later lead to cancer. Therefore, both CT and X-ray are generally avoided. MRI, on the other hand, does not deliver harmful radiations to the body but is generally expensive. This leaves ultrasound and thermal imaging as low cost, non-harmful imaging modalities to evaluate RA.

It has been shown that thermal imaging can be used for scanning, evaluating, and diagnosing patients with RA. Brenner [10] and Snekhalatha *et al.* [11] have conducted animal trials and concluded that thermal imaging can be used in the diagnoses of Rheumatoid Arthritis. Others have carried out studies comparing the thermal scans of healthy subjects with RA patients and concluded that statistically significant differences were found [9], [12]–[15]. Calin *et al.* [1] have concluded that thermal infrared imaging is a sensitive and reliable method, which makes it suitable for diagnosis, evaluation, and monitoring of a number of knee conditions. It can be used to monitor and evaluate osteoarthritis, rheumatoid arthritis, ligament, and tendon problems.

Rheumatoid Arthritis patients need to be regularly monitored. After regular checkups and evaluations, a dosage of the medicine is prescribed. In an auto-immune disease, the immune system of the body mistakenly starts attacking parts of the body itself. In RA the immune system attacks the flexible joints of the body (knee, wrist, finger, and hand joints). The only medication that works is the immune system suppressant, but suppressing the immune system too much makes the patient vulnerable to other diseases. Therefore, it is very important that the dosage of the medication is regularly evaluated and adjusted. If the medication dosage given is insufficient, the dosage of the medicine can be increased. On the other hand, if the pain in the joints decreases and the patient feels better, the dosage may be decreased. Thus, regular scans need to be carried out and compared with each other. It is difficult to say whether all the internal and external factors have remained the same when two scans are taken some time apart. In such a situation, it is not feasible to compare the absolute thermal values of the two scans. Fig. 1 shows a sequence of thermal scans acquired within few minutes. The figure shows the box plot of only the hand region where the temperature of the hand can be seen to be steadily rising over time. There is a difference of approximately 2°C between the first and the last thermal scan. The thermal scans used in this work have been acquired using a low-cost FLIR thermal camera *FLIR ONE Pro*.

The purpose of this paper is to investigate whether the relative difference between different regions of the hand stays the same even when the absolute temperature changes while scanning due to thermal sensor instability. In this paper we will show that although the absolute temperatures might be different, the relative difference between the temperatures remains the same; therefore, instead of using the absolute temperatures, we can use relative temperatures to provide a basis for examination of regions over time.

II. Method

A wooden box was designed, and the camera was placed on top of the box with a hole through which the thermal camera could acquire thermal scan of the hand placed beneath (see Fig. 2). The distance between the camera and the hand was around 32 cm for the scan 3(a) while the distance between the hand and camera was around 16 cm for scan 3(b). The box was created so that the distance between the hand and the thermal camera could be kept constant. A series of scans were acquired (see Fig. 3) using the setup shown in Figs. 2.

Fig. 4 shows the thermal distribution of the hand temperature using a boxplot. The background was removed and only the thermal values of the hand were used in the computation. The hand was segmented, and the background was removed using the algorithm detailed in the next paragraph. Many scans were acquired over time but only the scans that showed a marked difference between the thermal values were selected for comparison. For this reason, only two images from each set are shown in Fig. 4. The box-plot figures show that there is a marked difference in the absolute temperature values between the scans.

The hand segmentation algorithms utilize the points manually marked on the hand (see Fig. 5). A centered window of size 5x5 was placed on a point and the intensities within the window were extracted. This process was repeated for all the 15 points marked on the hand. This provided a total of $15 \times 25 = 375$ thermal values. Let the thermal values on

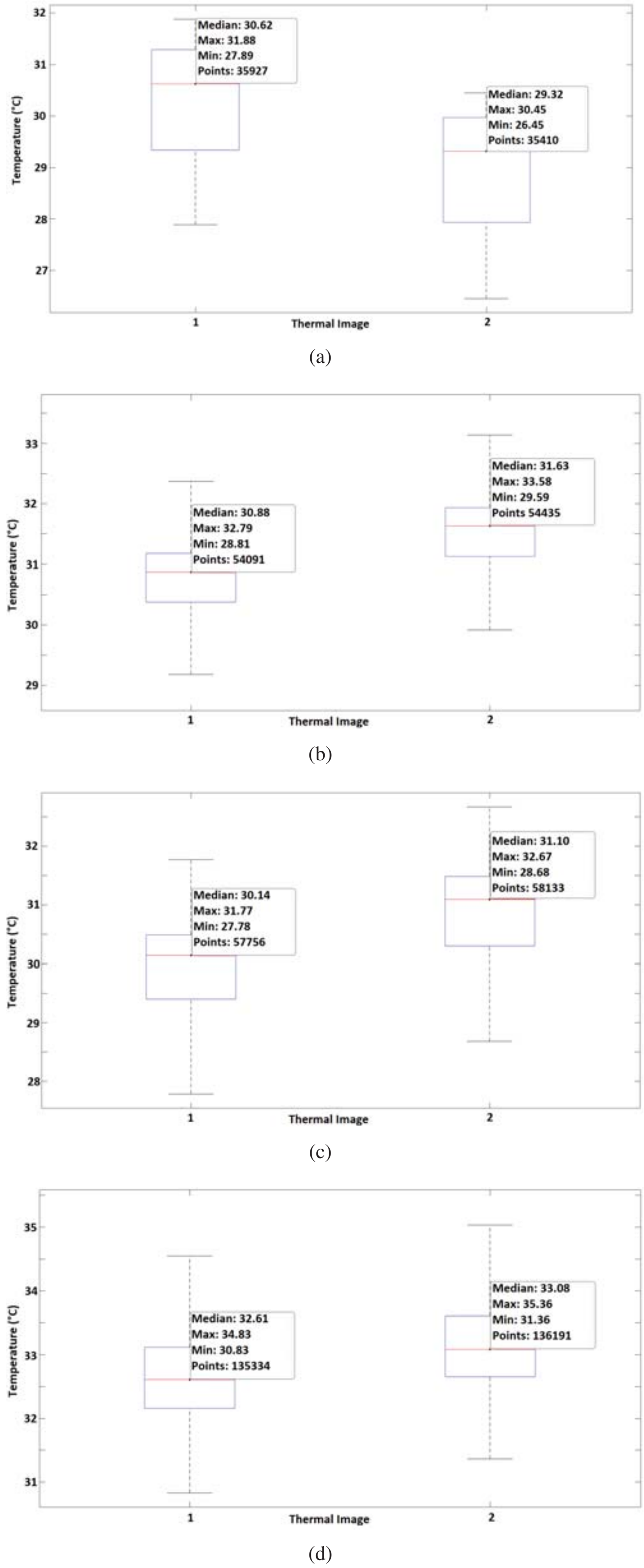


Fig. 4 Box plot of temperature distribution of hand

Fig. 5 Schematic diagram of the marked points on hand

the hand be denoted by t_i where $i = 1, 2, \ldots, 375$. Using these thermal values, the mean temperature μ of the hand was computed using (1). A straight forward strategy was used to get the interval of the thermal distribution of the hand temperature. The hand temperature interval was found by $\mu \pm 2°$. Thus, the temperature interval was $[\mu - 2°, \mu - 2°]$. Any thermal value that lays within the interval belonged to the hand while thermal values outside the interval belonged to the background. Such a strategy provided meaningful results as can be seen in Fig. 7.

$$\mu = \frac{\sum_{i=1}^{375} t_i}{375} \tag{1}$$

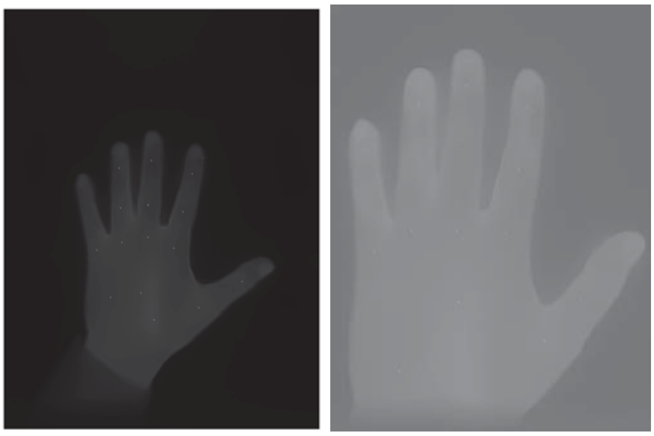
The aim was to show that even though the absolute temperature was different, the relative difference between the regions of the hand was preserved. To demonstrate this, a set of points was manually labeled on the hand. It was ensured that the hand did not move because we aimed to monitor the exact same spot over time. The approximate location of the points is shown in the schematic diagram (see Fig. 5). Three points each (a total of 9 points) were placed on the index finger, middle finger, and ring finger (see Fig. 5). Additional three points were placed on the palm region, and two points were placed on the thumb while one point was placed on the little finger. Hence, a total of 15 points were marked on the hand. Using such a configuration, the whole hand could be covered by the points. This provided a more reliable evaluation of the relative difference between different regions of the hand. The total number of relative differences between all the 15 points 105.

III. Results

A comparison of the thermal scans that were acquired within the same measurement sequence was carried out. This means that a series of thermal images were acquired without moving the hand or shutting down the camera. This made it difficult to compare two images in a sequence or to decide which image to use or which image provided the most accurate absolute temperature because the absolute temperature value differed from image to image[1] (see Fig. 1).

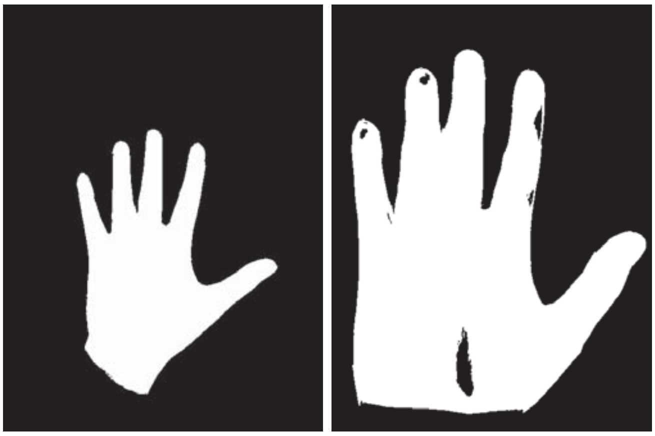
It was shown that although the absolute temperature might differ from image to image, the relative difference between

[1]It is to be noted here that the data sheet of the low-cost thermal camera mentions that the thermal sensors require some time to adjust to a stable reading.



(a) a (b) b

Fig. 6 Selected point on the hand



(a) b (b) d

Fig. 7 Segmentation of the hand

different regions of the target anatomical structure (in this case a hand) remained similar. As part of the experiments outlined here, we acquired four sets of scans in total. In three of the scan sets, the distance between the camera and the hand was around 32 cm while it was 16 cm for the fourth scan set. No special precaution was taken to keep the external environmental factors constant. A FLIR One Pro thermal camera was used to acquire the thermal images of the hand. The thermal resolution of the camera was 160×120 pixels with a temperature range of -20°C to 40°C. The thermal image obtained with camera had a resolution of 640×480. The Horizontal Field of View (FOV) was $50^\circ \pm 1^\circ$ while the Vertical FOV was $43^\circ \pm 1^\circ$ with a focus of 15 cm. The visual image resolution was 1440×1080 pixels.

To show the relative difference between the points, the difference of one point against all the other points was computed. The total combination of the relative differences between all the points was thus 105. The same process was repeated for all the four sets. For this paper only two representative scans from each set were chosen for comparison to each other. No comparison between the scans from different

TABLE I
MEAN AND STANDARD DEVIATION OF THE RELATIVE DIFFERENCE BETWEEN THE CORRESPONDING POINTS OF THE SCANS OF THE SAME SET

Datasets	Mean (°C)	Std-Dev
Set 1	0.12	0.09
Set 2	0.14	0.10
Set 3	0.15	0.10
Set 4	0.22	0.15

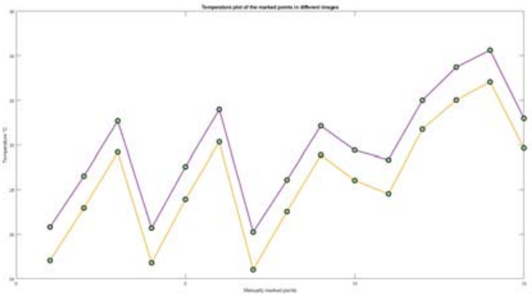
sets were drawn. The relative difference between scans across different sets was not computed as no precaution was taken to keep the temperature of the hand (both internal and external factors) constant when different sets were acquired. As a result, this evaluation focuses on comparing the relative difference between scans within a set. In future work, we intend to extend our focus to comparing scans acquired in different sequences. The graphs in Fig. 8 show that although there is a difference in the absolute temperature of the hand in two scans (see Figs. 8(a), 8(c), 8(e), 8(g)), the graphical pattern of the points with respect to each other remains similar. The similar pattern is an indication that the relative difference between the points on the scans remains. Figs. 8(b), 8(d), 8(f), 8(h) show the magnitude of the absolute difference for all the 105 points between the scans. The pattern in Figs. 8(b), 8(d), 8(f), 8(h) is not important; the essential point to note is the strength of the difference. The relative difference between 105 points from the first scan are computed; then, the 105 relative differences from the second scan are computed. These 105 relative differences from both scans are subtracted from each other. This difference is what has been plotted in Figs. 8(b), 8(d), 8(f), 8(h). Table I shows the mean and the standard deviation of the difference between the two scans. A lower mean and standard deviation indicate that the relative difference between the two scans remains. The quantity of the difference between the two sets can also be seen in Table I.

In some circumstances the relative differences are not preserved as can be seen in Fig. 9. It will require a more detailed investigation to analyze the circumstances under which the relative differences are not be preserved.

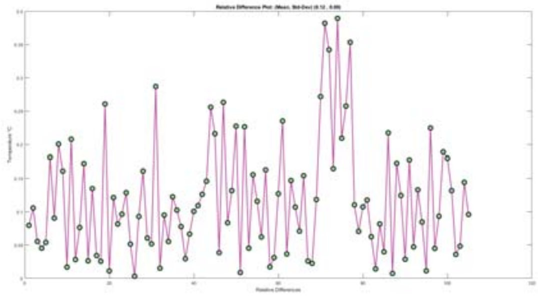
IV. Conclusion

Rheumatoid Arthritis is an autoimmune disease whose patients need to be regularly monitored. After regular checkups and evaluations, appropriate dosage of the medicine can be prescribed. A meaningful comparison of the thermal scans performed between visits is important. Low cost thermal cameras can be used to provide cheap and radiation free scans. However, the quality of the thermal values acquired by low cost thermal cameras depends on several factors. This makes comparing the absolute thermal values unfeasible as they cannot be relied upon. However, it has been shown in this paper that although the absolute thermal values cannot be relied upon, the relative difference between the different parts of the hand remains similar. Using the relative difference makes it possible to meaningfully compare thermal scans taken at different times.

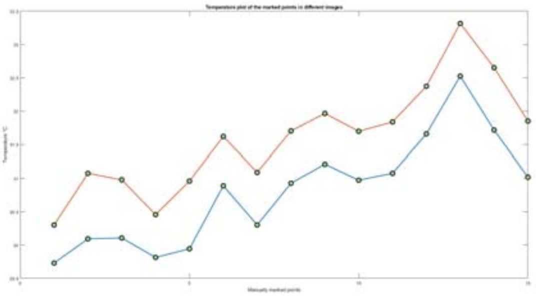
Four set of scans were acquired using a low-cost thermal camera. Two images from each set were selected and the



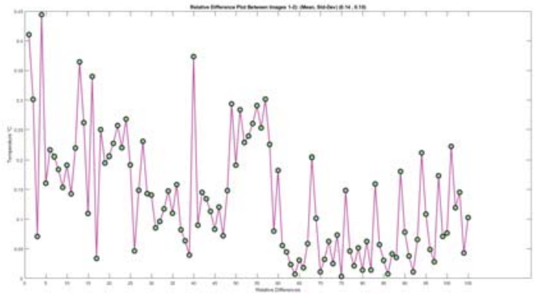
(a) 1a



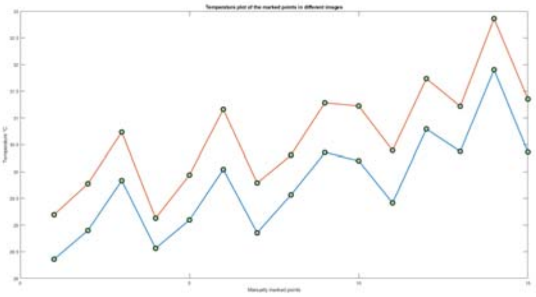
(b) 1b



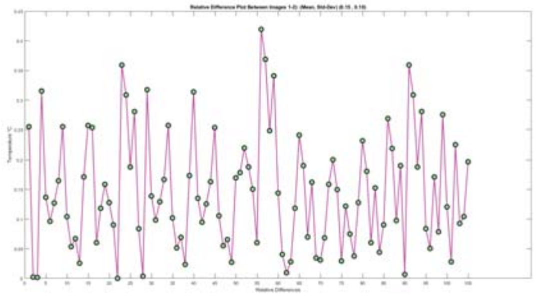
(c) 2a



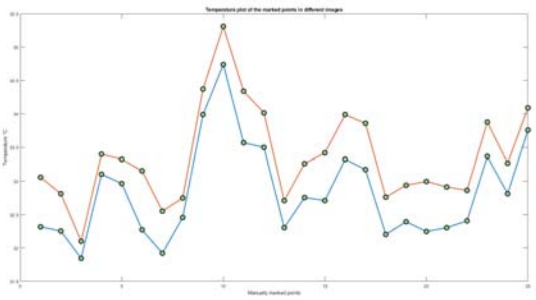
(d) 2b



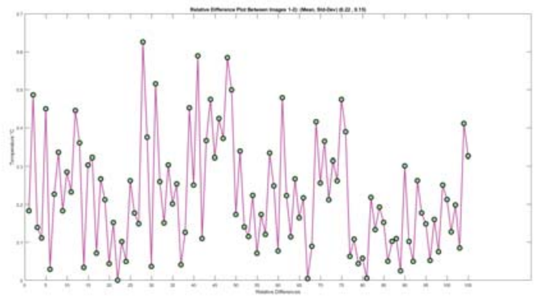
(e) 3a



(f) 3b

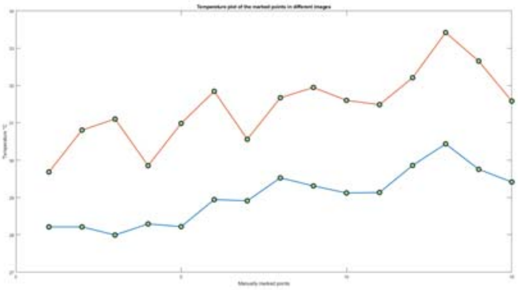


(g) 4a

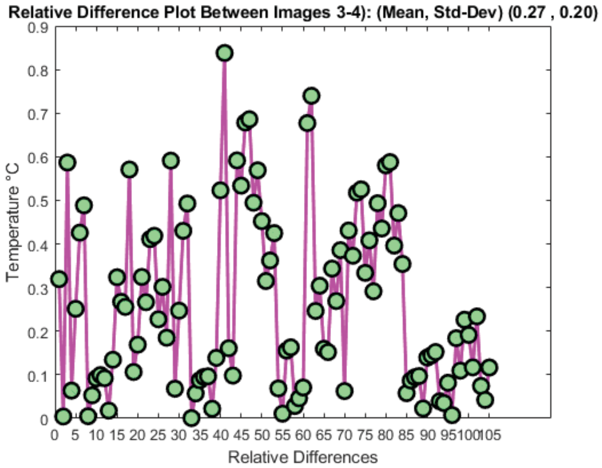


(h) 4b

Fig. 8 Relative difference between thermal values of the selected points



(a)



(b)

Fig. 9 Unpreserved relative differences

relative difference between the scans within each set were computed. The results show that although there is a marked difference between the absolute thermal values, the relative difference between the different regions of the scans remains small. This indicates that the relative differences are preserved and that the scans can be compared to each other even if the absolute thermal values of the scans differ. However, there are cases as shown in Fig. 9 where the relative differences are not preserved which needs further investigation.

In future work, we intend to compare a larger number of thermal scans from the same measurement sequence to further establish that the relative temperature differences remain. We then intend to extend our investigation to the comparison of thermal scans extracted from different measurement sequences.

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