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# Algorithm for Analyzing Thermal Images of Laser Irradiated Human Skin

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**Abstract**

**Introduction:** Tracking temporal changes of temperature during laser skin treatment plays an important role in improving the process of laser skin treatment itself. There are a number of methods to analyze temperature's temporal dependency during laser skin treatment; some of those methods depend on imaging the skin with thermal cameras. However, the use of thermal cameras exhibits specific problems, including the ability to track laser-skin interaction spot. This paper is dedicated to solve that problem using digital image processing program coded with Matlab.

**Methods:** The measurements were taken for 15 native Syrian subjects of different sex, age and skin tones, the treated ailment was port wine stain. The clinical work (laser exposure) was performed in Damascus University, hospital of dermatology. The treatment was observed by thermal camera and analyzed using the proposed Matlab coded tracking system.

**Results:** For all the subjects, the treatment laser spot was tracked and the curves of skin temperature change with time where calculated by the use of the proposed algorithm, then the active time was calculated for each subject. The algorithm proved practical and robust.

**Conclusion:** The proposed algorithm proved to be efficient and can be used to support future researchers with capability to measure the temperature with high frame rate.

**Keywords:** laser; skin treatment; digital image processing; thermal imaging; human skin

## Introduction

As the major path to convey laser energy to treat skin areas associated with specific types of dermatological disorders is through heat generated from photons absorption, tracking skin's temperature during those different types of laser's skin treatments is, of course, of critical importance to evaluate the treatment processes of interest.[1-3] Within this context, using thermal cameras, as the major device to measure that temperature, was favored by some works over using other types of sensors when specific conditions are required.[4,5]

However, the output of thermal cameras, i.e. the sequence of thermal digital images, requires an image-processing stage to extract the maximum temperature temporal variations on skin laser's spot. This stage depends majorly on tracking the laser spot since the spot's location during the imaging stage is not stationary over time. The reasons behind this spatial movement of laser's spot with time can be due to patient reaction movement to laser pulses, the laser's hand-piece movement and rotation (i.e. the physician control to illuminate skin's area of interest), and in some cases the thermal camera's movement during the treatment process.

In this work, a tracking image processing system was proposed to track laser's spot on skin during actual skin treatment. Such tracking system can be useful in research (Verkruysse et al[6] and Tunnell et al[7]), medical devices development, and practical treatments and physicians' evaluation.

As a final note in this section, it is important to mention that the major goal of this work is not tracking the laser spot by means of its spatial locations; the ultimate goal is to track the laser spot, whether is visible or not, in means of its thermal effect. That is, this work is about measuring the temperature changes generated by a moving laser spot on skin, which requires tracking the spot. That is what differs this work from other works,[8] where a visible camera can suffice for pure means of spatial tracking.

## Methods

The clinical work was conducted at the Hospital of Dermatology of Damascus University (registration number: /88/ in 30/09/2013/Damascus University). The Dye laser 595 nm (Synosure V Star, USA) is capable of producing pulses between 0.5 ms and 40 ms. In this work we used 0.5 ms. Fluence measurements were performed by an integrated power-meter within the laser system. Figure 1 shows the experimental setup.

The thermal imager was Fluke Ti55, which had the following specifications: its resolution was 320 × 240 pixels,

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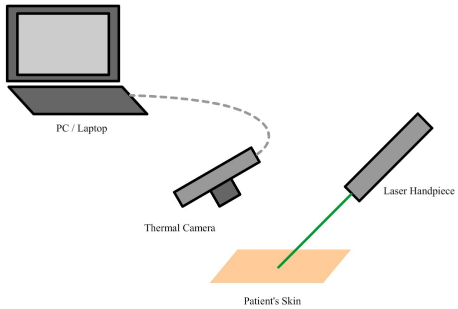


**Figure 1.** The experimental setup, the thermal camera was set to capture the temperature rise on patient's skin during laser treatment. The captured video has been transferred to the computer in real time.

its maximum frame rate was 60 fps, and its spectral band was 8 to 14 µm. The camera's thermal sensitivity was less or equal 0.05ºC at 30ºC; the camera's accuracy was ± 2°C or ± 2%, whichever was greater, and the focusing mechanism was single finger manual focus.

The following values were entered in the thermal camera's options and in the images acquisition software on PC:

- The picture mode was chosen as grayscale to ease the interpolation of each pixel value, which was a number between 0 and 255 in the case of grayscale images, with its associated temperature. The associated temperature could be determined linearly based on the minimum and maximum temperatures on the taken scale.
- The minimum and maximum temperatures of the camera's scale were chosen depending on each subject's case (majorly depending on both the presence of cooling, and skin tone). It is important to point out that those values of temperature should be inputted as fixed values for each measurement, i.e. not auto where the camera set the scale automatically depending on the target's maximum and minimum temperatures.
- Emissivity was fixed at 0.98 where skin is considered approximately very close to black body in terms of thermal radiation.[9]
- The thermal sequences were recorded as videos to acquire the fastest possible frame rate for the thermal camera we used.
- The frame rate mode was fixed at NTSC (29.97 frame per second), NTCS frame rate is the maximum value which can be recorded on a PC from this camera.

The measurements were taken for 15 native Syrian subjects of different sex, age and skin tones, the treated ailment was port wine stain. The laser parameters were identical for all subjects: the energy value was 7.1 J, pulse duration was 0.5 ms, and the laser spot was 7 mm. It is important to notify that skin tones, through this work, were labeled following Fitzpatrick skin-typing scale.[10]

Matlab provides several functions that can be used to create different types of digital processing systems. In this work, we used Matlab (version 2011a) to write the program of our proposed tracking system. This tracking system consists of two major steps:

Importing the thermal video recorded by the thermal camera during Laser skin treatment and converting it to sequence of frames (fixed images at specific frame rate).

↓

Calculating each frame's associated instant for the frame rate value used during the imaging stage.

↓

Excluding the frames with no thermal data of laser interaction with skin (i.e. the frames with no laser spot within).

↓

Rescaling each gray level value of each pixel in the frames of interest to its associated temperature value. This process is based on the minimum/maximum temperature values chosen in camera's options before the imaging stage.

↓

Display the frames at suitable fast frame rate (i.e. custom frame rate, which is faster than the imaging frame rate) for the user to pick the laser spot to be targeted and tracked (The spot should be isolated and clear during its lifetime).

↓

Depending on the targeted spot size, creating rectangle in each frame whose center is identical to the tracked laser spot's center; this rectangle's center value changes from frame to frame to be identical to the coordinates of the spot's central temperature. The rectangles of each original frame are grouped in a new frames sequence, which only includes those rectangles.

↓

As the new frames sequence includes only the targeted spot, it is now possible to derive many associated measurements for that spot. In this work, we determined the maximum temperature of the spot, where those values were displayed as a curve of temperature changes with time.

↓

For the targeted spot and depending on its maximum temperature changes with time, useful parameters for the treatment process can be calculated. In our work we picked "active time" parameter to be calculated and presented in the results section.

**Figure 2.** The Programming Steps for the Proposed Digital Image Processing Tracking System.

- To read the sequences of thermal imaging which have been taken for none-static area of skin during laser treatment. Then to link the values of temperature and time to the different elements of the sequence.
- To isolate a sub-area within each frame of the sequence, where this sub-area contains only a chosen laser spot on it. Therefore, a new sequence will be created that will allow the calculation temperature changes with time as example.

Figure 2 is a figurative flow chart that shows the steps of the process in more details. The captured thermal videos were converted to sequences of frames (pictures) using frame rate's value. Each frame can be assigned to its exact instance. As the thermal data is encoded in the frames as grayscale values (0-255), we add a stage to rescale those values to be equal to their related temperature and that can be done depending on the settings of maximum and minimum temperature values in the thermal camera setup before capturing the data. Then an interactive stage can be initialized, where the frames are displayed with fast frame rate to ask the user to determine which spot he wants to track, the spot should be clear and isolated from the other spots. After acquiring the initial center of that spot the tracking system sets a rectangle to envelope it. At each frame the rectangle moves with the spot tracking its central temperature, and during that and from frame to frame, each rectangle is stored at new frames sequence. Now that we have new frames sequence which only contains the spot, we can proceed to extract the time of data we want. As an example, we can track the highest temperature temporal change. Then depending on the plot we got we can calculate the active time[5] (active time is the duration of laser pulse in which temperature value is above the damage threshold of skin) or thermal relaxation time (TRT),[4,11] as example. Figure 1 shows the flow chart of the developed algorithm.

The functions that we used in Matlab are those that deals with images as two-dimensional matrixes of integer numbers. That is, the data was analyzed, modified and the wanted curves were extracted, by dealing with the thermal images as scaled numerical sequences.

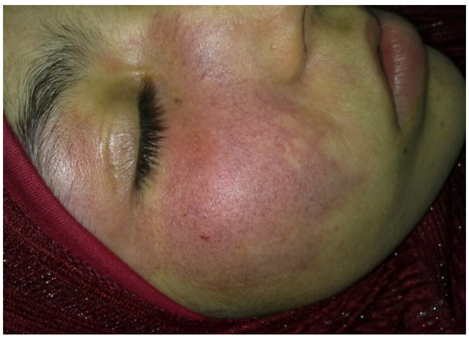

Figure 3. Image of one ailment on which, we used our tracking system during the laser treatment.

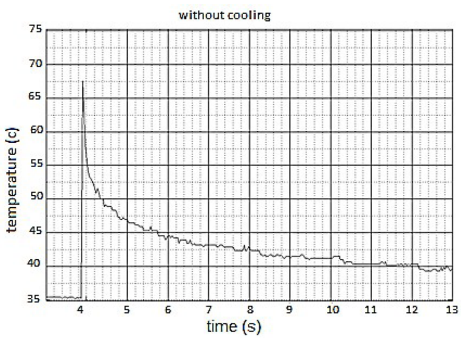


Figure 4. Skin Temperature vs. Time After Laser Irradiation on a Subject With Skin Tone 4 Without Cooling.

## Results and Discussion

The temperature measurements' accuracy on this work depends on the accuracy of the camera used, thus the accuracy in all the next measurements is ± 2°C. Figure 3 shows a picture of one subject with port wine stain before the treatment. The steps of Matlab code to obtain temperature temporal curve is identical to what was described in the previous section. We implemented that code on videos taken for each laser irradiation process on each subject. Figure 4 shows temperature temporal curve during laser pulse on one of the subjects, the curve was plotted based on our tracking system with signal-programmed function. This curve is important to predict the maximum temperature values and the duration of active time or any other desired temporal parameter. Tables 1 and 2 show the active time measured depending on all temperature temporal curves obtained for all cases, calculating the active time was automated as well. The results are consistent with Toumi et al[5] where cooling decreased the active time and so did the skin tone darkness. As we mentioned before we chose active time as the main parameter based on previous work. The system can measure any other desired parameter if based on the temporal or spatial change of skin temperature over both pulse duration and laser spot. The experimental study works carried

**Table 1.** Active Time for Different Subjects With Cooling

| Skin Tone | Active Time (s) |
|---|---|
| 2 | 2.15 |
| 2-3 | 1.15 |
| 3 | 0.045 |
| 3 | 0.044 |
| 3 | 0.044 |
| 4 | 0.04 |
| 4 | 0.039 |

**Table 2.** Active Time for Different Subjects Without Cooling

| Skin Tone | Active time (s) |
|---|---|
| 2 | 6.5 |
| 2-3 | 6 |
| 3 | 5.8 |
| 3 | 5.6 |
| 3 | 5.5 |
| 3 | 5.4 |
| 4 | 5.2 |
| 4 | 5.2 |

out in this study are unique in its perspective and cannot be compared directly with other works more than what is discussed in the background section.

Even though the focus of this work was about tracking single pulse on the laser, it is clear that the program in principle is able to track temperature temporal changes in the case the physician chooses a treatment method that implement a series of laser shots to accumulate energy on specific spot. The program structure is adaptive to adding margins to spot size and to keep scanning the maximum temperature of a specific area during the whole treatment duration for that area.

## Comparison With Other Methods

To the date this paper is written, it is widely noted that commercial skin-treatment laser systems do not provide the luxury of analyzing skin-laser interaction during the treatment process. Those systems rely mostly on the human factor, namely the experience of the laser's operator. Incorporating a monitoring system, such as the one proposed in this work, would significantly improve the treatment efficiency. Nevertheless, the current approaches to build such monitoring systems, lack interest on a very important parameter that dominates the efficiency of the treatment, namely active time.[5]

Compared to Noh et al[8] and Altshuler et al,[12] which used visible light to evaluate the operator proficiency or evaluate the efficiency in laser skin treatment, our method provides thermal readings along the treatment procedure. As mentioned before, thermal parameters like active time are the ones dominating laser-skin interaction in port wine stain's treatment.

Works that implement thermal vision to analyze the skin treatment process can be found, as in[13-15] (those works are focused on area temperature observing), or to detect the presence of vascular disorders as in.[16] Our method is targeted toward the laser treatment itself, and it implements accurate single beam tracking assuming considerable movements that would translate the laser beam within the camera field of view during the treatment. Furthermore, we consider that the single parameter that our method calculates (Active time), is of crucial importance in the treatment process.[5] Nevertheless, our proposed algorithm can be used to calculate any custom thermal-temporal parameter when needed.

## Conclusion

In this work, a practical digital image processing system to analyze heat temporal change on skin during laser treatment process was described. The system proved to be efficient and can be used to support future researchers with capability to measure the temperature with high frame rate. The system can be integrated within new medical lasers systems, which depend on thermal interaction, where it can serve as a tool in real time adaptive treatment processes.

## Ethical Considerations

This study have been approved by ethical committee of the Hospital of Dermatology of Damascus University.

## Conflict of Interests

The authors declare no conflict of interest in this work.

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