Computers in Biology and Medicine 76 (2016) 1–6

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Image-guided automatic triggering of a fractional CO_2 laser in aesthetic procedures

Sławomir Wilczyński [a,*], Robert Koprowski [b], Barbara K. Wiernek [c], Barbara Błońska-Fajfrowska [a]

[a] Department of Basic Biomedical Science, School of Pharmacy with the Division of Laboratory Medicine, Medical University of Silesia in Katowice, Poland
[b] Department of Biomedical Computer Systems, University of Silesia, Faculty of Computer Science and Materials Science, Institute of Computer Science, Będzińska Street 39, Sosnowiec 41-200, Poland
[c] Duke University Medical Center, Durham, NC, USA

ARTICLE INFO

Article history:
Received 31 March 2016
Received in revised form
8 June 2016
Accepted 9 June 2016

Keywords:
Ablative lasers
Automatic laser triggering
CO_2 laser
Image processing

ABSTRACT

Background: Laser procedures in dermatology and aesthetic medicine are associated with the need for manual laser triggering. This leads to pulse overlapping and side effects.
Methods: Automatic laser triggering based on image analysis can provide a secure fit to each successive doses of radiation. A fractional CO_2 laser was used in the study. 500 images of the human skin of healthy subjects were acquired.
Automatic triggering was initiated by an application together with a camera which tracks and analyses the skin in visible light. The tracking algorithm uses the methods of image analysis to overlap images. After locating the characteristic points in analysed adjacent areas, the correspondence of graphs is found. The point coordinates derived from the images are the vertices of graphs with respect to which isomorphism is sought. When the correspondence of graphs is found, it is possible to overlap the neighbouring parts of the image.
Results: The proposed method of laser triggering owing to the automatic image fitting method allows for 100% repeatability. To meet this requirement, there must be at least 13 graph vertices obtained from the image. For this number of vertices, the time of analysis of a single image is less than 0.5 s.
Conclusions: The proposed method, applied in practice, may help reduce the number of side effects during dermatological laser procedures resulting from laser pulse overlapping. In addition, it reduces treatment time and enables to propose new techniques of treatment through controlled, precise laser pulse overlapping.

1. Introduction

Efficacy and side effects of medical aesthetic laser procedures are highly operator dependent – both when using ablative and non-ablative lasers. A key factor in laser treatments is the appropriate selection of laser parameters and the treatment technique. One of the most common causes of side effects is stacking of laser pulses [1,2]. Besides, when pulses stack, patients report greater discomfort, a burning sensation, and pain [3]. However, some procedures involve laser pulse overlapping which results from deeper laser penetration in the dermis, especially in low-power devices [3].

When laser pulses are overlapped or stacked without the removal of ablated tissue and rehydration of the underlying skin, a heat sink will occur, resulting in focally increased heat penetration. This may happen in the case of too rapid pulse frequency or too slow operator's hand speed [3]. If CO_2 laser passes are repeated (overlapped), the dermal collagen will be dehydrated and coagulated, which subsequently limits the penetration of laser energy having an impact on both the ablative effect and the incidental thermal injury of subsequent passes. Due to the fact that a large part of the heat in subsequent passes is not actually used to ablate the tissue, there is an increase in thermal loading of tissue. More thermal scattering which occurs in the reticular dermis also results in a potential increase in scarring. Since the resurfaced skin heals by re-epithelialization through intact appendages, these appendageal reservoirs will be destroyed if the laser penetrates the skin too deeply. The base of the appendages is in the mid or lower reticular dermis. Resurfacing to a greater depth leads to an increased risk of scarring [3,4].

On the one hand, laser pulse overlapping can be seen as a negative phenomenon (increasing the risk of side effects). On the

* Corresponding author.
E-mail address: swilczynski@sum.edu.pl (S. Wilczyński).

http://dx.doi.org/10.1016/j.compbiomed.2016.06.012
0010-4825/© 2016 Elsevier Ltd. All rights reserved.

other hand, it enables to multiply the laser energy, which can produce positive therapeutic effects. Pulse overlapping is used, inter alia, in laser therapy of Port Wine Stains (PWS). Koster et al. [1] show that pulse overlapping can increase the effectiveness of the treatment of PWS while minimising side effects. It should be noted, however, that in the case of PWS there is strong vasodilation around lesion, which may promote the distribution of heat within the tissue minimising side effects resulting from pulse overlapping [1]. In other cases, pulse overlapping will generally induce side effects.

Whatever the effect, positive or (usually) negative, two neighbouring pulses cannot be treated as single separate doses of energy but they should be treated synergistically.

It should be also noted that under controlled laboratory conditions it is possible to apply laser pulses very precisely while under actual treatment conditions the precision of moving the laser head is much lower. Treatments carried out by using a CO_2 laser indicate that even for a very highly skilled operator, the surface of pulses which are not ideally arranged is approximately 20%, of which about 18% is the surface that was omitted and about 2% is the surface where pulse overlapping occurred [5]. Importantly, in the case of a CO_2 laser, each subsequent pulse leaves a clear trace on the skin. Therefore, it should be expected that in the case of non-ablative lasers, where each successive laser pulse does not leave a trace on the skin, the surface that is exposed to imprecise alignment of pulses will be much greater. Sample infra-red images of the facial skin treated by means of a CO_2 laser are shown in Fig. 1. The square-like areas on the patient's forehead are subsequent doses of radiation applied by an experienced operator.

Pulse overlapping or leaving untreated areas can be prevented by using a camera which analyses an image in visible light. Based on the results of image analysis, it is possible to trigger the laser automatically. The proposed method will provide a secure fit of each successive dose of radiation. This will be achieved through analysis of images (their overlapping) and automatic laser triggering.

The aim of this study was to develop a system for automatic triggering of subsequent laser doses allowing for a perfect fit of successive laser pulses on the skin.

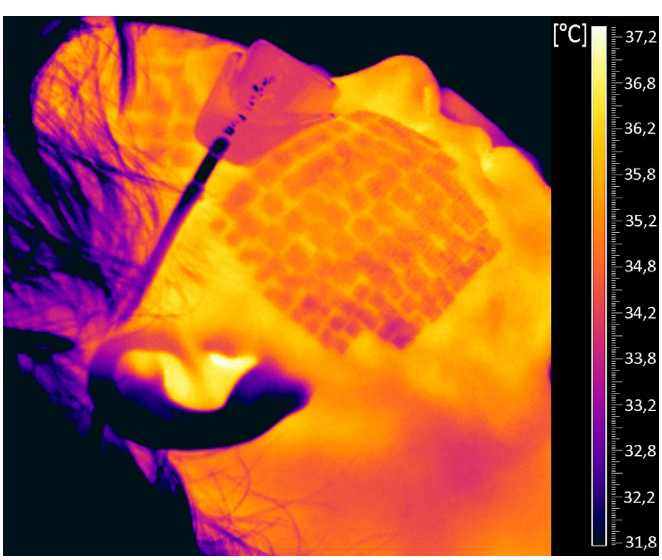

Fig. 1. Sample face image taken 10 s after the laser procedure in infra-red light by Flir SC5200 infra-red camera. The image shows the overlapping and untreated areas.

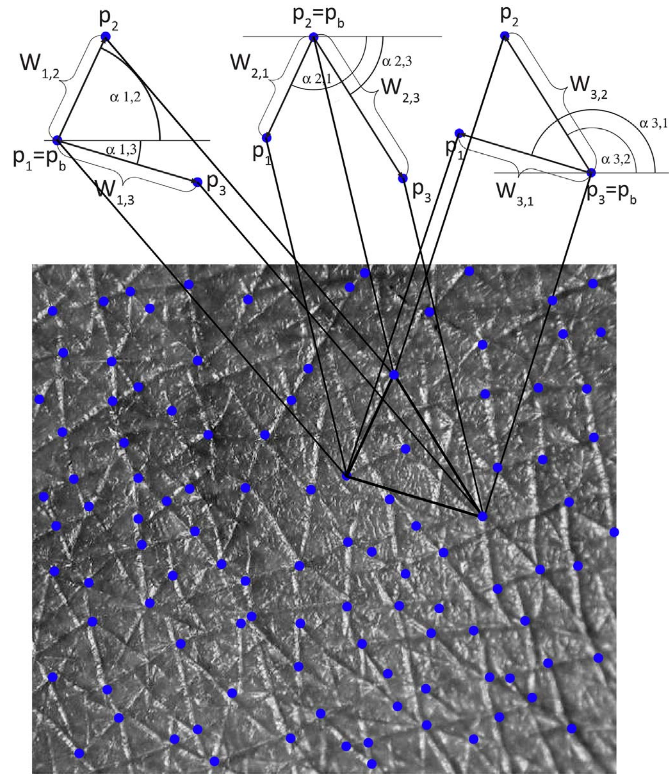

Fig. 2. Method for determining the graph parameters: the ratio of distances between vertices, angles between the graph vertices (illustrative image).

2. Material and method

Image overlapping is implemented based on isomorphism of graphs. Graphs are structures that are the result of graphical interpretation of skin ridges (Fig. 2). The tops of the skin ridges create graphs. The mathematical description of the graph includes determination of the ratio of the distance between the vertices of the graph and the angles formed by these vertices. This allows for matching the successive images containing graphs even when the quality of the recorded images is not perfect. Such a situation occurs during laser treatments performed with the proposed technique where the laser head with an attached camera moving across the skin can observe the same skin area at different angles and in different lighting conditions.

The graph isomorphism takes place when the structure of the compared graphs G_a and G_b is identical and the characteristics (attributes) assigned to the edges and vertices of graphs are the same [6–8]. However, in many cases of image analysis and processing (including this one), there is a need to find isomorphism with respect to a subgraph, so-called subgraph isomorphism. This issue is important in image processing since the information about the graph is most often incomplete – redundant (numerous interferences) or non-measured (non-detected characteristic elements, points, edges which form the graph). Inaccurate correspondence of graphs allows for variation in both the values of graph attributes and their structure. In addition, it complicates determination of measures of similarity between graphs or subgraphs. The time of analysis of graph correspondence does not exceed 0.5 s with a small number of graph vertices (attributes), about 20, 30.

2.1. Materials

500 images were acquired in order to analyse the correctness of laser triggering. These were the images of the hand and face areas