Rapid extraction Quick Extracting of the Hottest or Coldest Regions of Medical Thermographic Images

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Abstract

Early detection of breast tumors, feet pre ulcers diagnosing in diabetic patients, and identifying the location of pain in patients are essential to physicians. Hot or cold regions in medical thermographic images have potential to be suspicious. Hence extracting the hottest or coldest regions in body thermographic images is an important task. Lazy snapping is an interactive image cutout algorithm that can be applied to extract the hottest or coldest regions in body thermographic images quickly with easy detailed adjustment. The most important advantage of this technique is that it can provide the results for physicians in real time readily. In other words, it is a good interactive image segmentation algorithm since it has two basic characteristics; 1) the algorithm produces intuitive segmentation that reflects the user intent with given a certain user input and 2) the algorithm is efficient enough to provide instant visual feedback. Comparing to other methods used by the authors for segmentation of breast thermograms such as K means, fuzzy c means, level set and mean shift algorithms, lazy snapping was more user-friendly and could provide instant visual feedback. In this study, twelve test cases were presented and by applying lazy snapping algorithm, the hottest or coldest regions were extracted from the corresponding body thermographic images. The time taken to see the results varied from 7 to 30 seconds for these twelve cases. It was concluded that lazy snapping was much faster than other methods applied by the authors such as K means, fuzzy c means, level set and mean shift algorithms for segmentation.

Key words: Extracting, Lazy snapping, Hottest, Coldest, Thermography, Images

1. Introduction:

Nowadays, with advanced infrared cameras that can map thermal distribution of human body very accurately, thermography has been reconsidered and on par with the other medical modalities as an adjunctive technique to detect breast abnormalities, to determine where the pain is coming from and to warn ulceration in feet of diabetic patients. Infrared imaging or thermography is determined by displaying detailed skin temperature. It is a non-invasive and non-radiating technique for analyzing physiological functions associated to the regulated skin temperature. The technique involves the detection of infrared radiation that can be directly correlated with the temperature distribution of a defined body regions. In 1972, Thomas Tierney, expressed and presented that, “The medical specialists expressed that thermography, at this time, is in advance of the exploratory state as a diagnostic method in the coming fields: (1) Female breast pathology, (2) Extracranial vessel disorder, (3) Peripheral vascular disorder, (4) Musculoskeletal damage”.[1,2]. This promptly expanding technology is used for early detection of abnormalities in breasts females, for early detection of feet ulcers in diabetic patients and identifying the location of pain in patients. It identifies thermal irregularities such as hot spots related to the increased or decreased skin surface temperatures.

There is a correlation with both increased blood circulation and increased metabolism in cancerous tissues. Increased vascular flow is resulted of vascular proliferation correspondingly tumor related angiogenesis. Cancerous cells generate a chemical which indeed helps the growth of blood vessels feed the region where the tumor exists. Although, the sympathetic nervous system basically control the normal blood vessels but, in this situation the blood vessels become paralyzed, vaso-dilated or their sizes are widen. Increased blood in the area as a result of angiogenesis as well as vaso-dilation clearly introduce more heat, extractable by thermographic imaging technique. Numerous studies have been shown that thermal imaging is capable of measuring the heat signatures years before conventional technologies can identify a mass in female breasts [3-8]. It provides functional information on thermal and vascular conditions of the tissue. These functional changes are before beginning of structural changes that happen in a diseased or cancerous state. It is notable that physiological changes in tissue come before the pathological changes [9]. Thermography uses no radiation, compression of breast tissue. It is a completely safe early warning breast cancer detection system. Moreover, thermography has the potential to identify regions of plantar of feet that are at risk of ulceration in diabetic patients. In most diabetic patients, symptoms of ulcers are not observed until the ulcer is infected [41-43]. Ischemic foot and neuropathic foot are two complications of diabetic patients. Coldness is experienced in ischemic feet while hotness in neuropathic feet. The term "ischemic foot" indicates a lack of sufficient arterial blood circulation in foot to contribute the oxygen and nutrient needs necessary for the cells. Diabetes people may experience neuropathic feet due to the nerve injuries. Although, high blood sugar may harm nerve fibers throughout the body, but diabetic neuropathy commonly damages nerves in the legs and feet. Studies show that average temperature of the neuropathic foot in diabetic patients is higher than in patients without neuropathy [36-40]. Hence, displaying the map of skin temperature of plantar in diabetic patients is very beneficial to determine feet complications that sometimes lead to amputation. Thermography is very useful to warn early foot complications of diabetic patients, and also specifically helpful to identify the ischemic foot as well as the neuropathic foot [10-13]. In addition, thermography has potential to diagnose location of pain in different categories. It can provide data of pain quantitatively as it reports detail and deep thermal variations. However, no examination can provide data showing the detailed information about the location and the magnitude of the pain. It has been a problem to be differently recognized for years since it has been identified subjectively. In inflammatory pain situation, the inflammatory response is experienced which is a protected process to guard against infection and harm. The reaction involves alterations in blood circulation. Accordingly, thermal imaging has potential to obtain helpful informations regarding the inflammatory pain [14-15].

Image segmentation techniques can play a crucial role to segment and extract the hottest or the coldest regions in the clinical infrared images. For example, shape, size and borders of the hottest regions of the breast infrared images can help determining the features used to detect abnormalities. So far, several techniques have been applied in order to extract different regions especially the hottest regions from breast thermograms [16-18]. Observing the hottest regions or the coldest regions, potentially suspicious regions, of an infrared image in real time can be interesting for physicians. For instance, considering pain which has been diagnosed subjectively for many years. However, showing the location of pain in the thermal image of one patient, for example, with a back pain fast and quickly could be very essential. Lazy snapping method can be helpful in this matter which is very fast, user friendly and easy. This paper is organized as follows: Method of approach is explained in "Methodology" section, test results are presented in "Experimental Results and Discussion" section, and "Conclusion" section concludes the findings.

2. Methodology

Lazy Snapping is an interactive image algorithm that divides coarse and fine scale processing, accomplishing object condition and detailed adjustment effortless [19]. In addition, lazy Snapping contributes instant visual feedback, separating the divided contour to the accurate object boundary conveniently regardless of the existence of vague or low contrast edges. A set of intuitive user interface (UI) technique is performed to support adaptable control for the users.

The important task is to permit the user to concertedly collect the foreground object opposed to its background. The technique permits the user to apply lines and curves to indicate the expansion of the object of interest rather following boundary of the object. The mouse cursor is dragged while holding a button, and some lines on the image are markdown by a user to identify the hottest or the coldest region. This technique supports an interactive graph cut algorithm by maximizing both the color similarity inside the suspicious regions and the gradient along the boundary to optimize the suspicious regions boundaries.

2.1 Concepts in Graph Theory

Graph: A graph is a description of a group of items where some pairs of them have some link connections. A mathematical representation of a graph is given as $G = (V, E)$ where E denotes set of edges and V denotes set of vertices. A directed weighted graph involves a group of nodes V and a group of directed edges E that join them. Frequently nodes related to pixels, voxels or some features. In this study, we need to solve a labelling problem [20]. Here, a unique label x_i where $i \in V$, for each node is designated such that if $x_i \in foreground$ then $x_i = 1$ whereas if $x_i \in background$ then $x_i = 0$.

By applying optimization theory, the solution $X = \{x_i\}$ is obtained. For optimization part, Gibbs energy $E(X)$ is minimized.

$$E(X) = \sum_{i \in V} E_l(x_i) + \lambda \sum_{(i,j) \in \varepsilon} E_p(x_i , x_j) \quad (1)$$

where $E_l(x_i)$ is the likelihood energy and $E_p(x_i, x_j)$ the prior energy. The likelihood energy denotes the cost when the label of node i is x_i while the prior energy represents the cost when the labels of adjacent nodes i and j are x_i and x_j respectively. E_l or the likelihood energy encodes the color similarity of a node and shows whether the node belongs to foreground or background [21].

To calculate E_l, the following steps are obtained: 1) by *K* means technique, the colors in seeds of foreground and background are classified, 2) average of colors of foreground and background groups are calculated as $\{K_m^F\}$ and $\{K_n^B\}$ respectively, 3) the minimum distances, *d*, from its color $G(i)$ to foreground groups and background are computed as

$d_i^F = \min_m \|G(i) - \{K_m^F\}\|$ and $d_i^B = \min_n \|G(i) - \{K_n^B\}\|$ respectively [22].

where *m* is the number of the foreground components while *n* is for the background. Then $E_l(x_i)$ is obtained as Eq. (1)

$$\left\{\begin{matrix} E_l(x_i = 1) = 0 & E_l(x_i = 0) = \infty & \forall\, i \in F \\ E_l(x_i = 1) = \infty & E_l(x_i = 0) = 0 & \forall\, i \in B \\ E_l(x_i = 1) = \frac{d_i^F}{d_i^F + d_i^B} & E_l(x_i = 0) = \frac{d_i^B}{d_i^F + d_i^B} & \forall\, i \in U \end{matrix}\right\} \quad (2)$$

where U is uncertain region and defined as $U = V - \{F \cup B\}$. Prior energy or E_p is introduced by the energy caused by the gradient along the boundary of the object. The color gradient between two nodes *i* and *j* controls E_p , hence, we write

$$E_p(x_i, x_j) = |x_i - x_j| \,.\, h(G_{ij}) \quad (3)$$

where $h(G_{ij}) = \frac{1}{G_{ij}+1}$ and $G_{ij} = \|G(i) - G(j)\|^2$ is the L_2-Norm of the RGB color difference of two pixels *i* and *j*. Observing that $|x_i - x_j|$ provides us with the gradient information exclusively along the segmentation boundary. By the way, E_p is a penalty term when different labels are accredited for adjacent node. Larger E_p indicates that the colors of two nodes are more similar and consequently, the edge is less probable on the object boundary. The maxflow algorithm suggested by Boykov and Kolmogorov [21] is applied to minimize the energy *E*(*X*) in Eq. (1).

The flow chart of Lazy Snapping algorithm is demonstrated in Fig 1. As we see, firstly, the foreground and background regions were selected by marking seeds in each region. Secondly, the likelihood energy, $E_l(x_i)$, and the prior energy, $E_p(x_i, x_j)$ were computed and consequentely, the gibbs energy was obtained. Finally, the gibbs energy by using Maxflow algorithm was maximized.

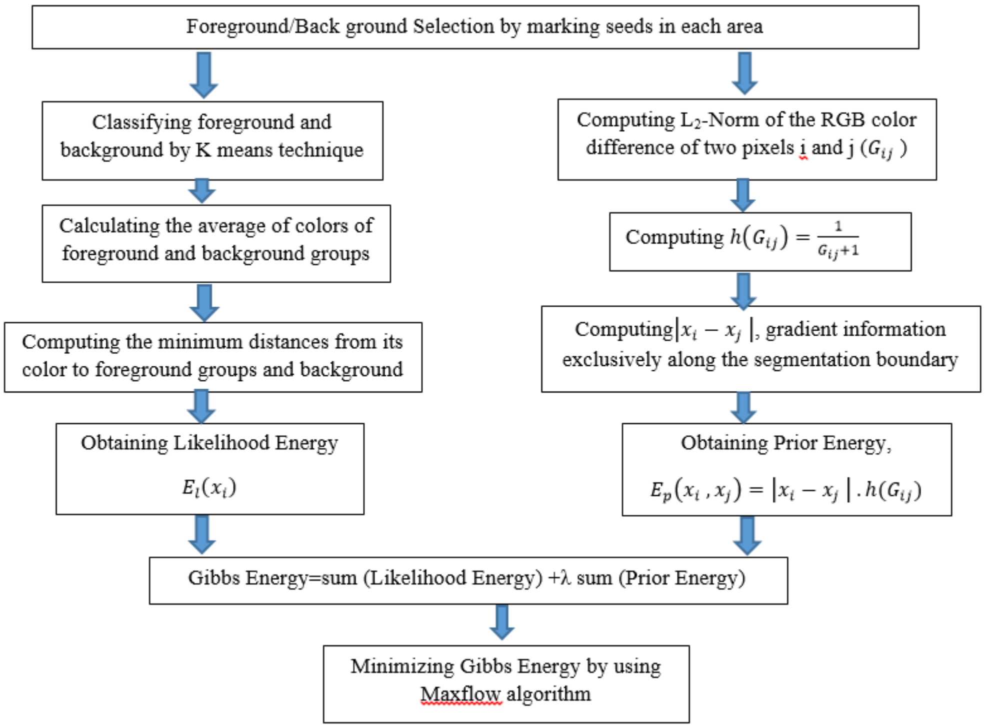


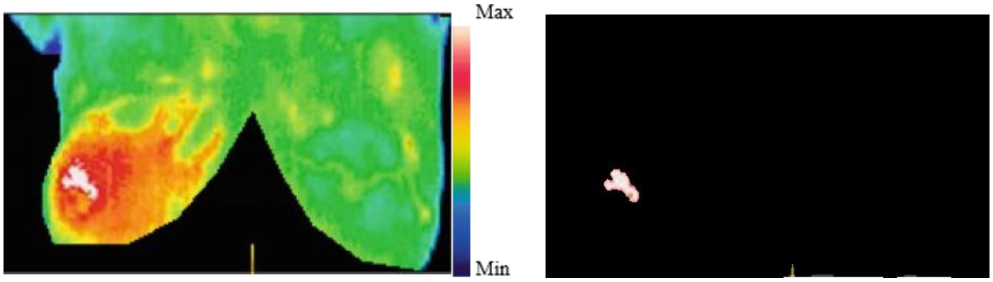
Fig. 1- Flow chart of Lazy Snapping Classifier

3. Experimental Results and Discussion

We presented twelve test cases in various diseases to show physicians who are interested to observe the ability of lazy snapping algorithm to extract abnormal sites in different clinical thermograms on real time. Cancerous cells, inflammations and infections appear as hot spots in breast thermograms and correspondent thermograms, respectively. While cold spots are experienced in ischemic feet. Moreover in neuropathic plantar thermograms of diabetic patients, we observed hot spots as areas with high risk of ulceration. Besides, pain shows up in body thermograms as hyperthermia regions. Twelve test cases in various diseases were demonstrated as follows:

Case 1: Inflammatory carcinoma [23]

An inflammatory carcinoma case was presented. Mammography did not diagnosed her disease at this stage. No clinical indications also were found at this stage. However, the routine check-up of breasts by thermography led to the diagnosis of inflammatory carcinoma in her right breast. Inflammatory breast disease cannot be detected by mammography and is most commonly found in younger women, the prognosis is always unsatisfactory. This earlier detection led ultimately to her longer life. Her thermographic image was demonstrated in Fig. 2a. The hottest region or the inflamed site was extracted by lazy snapping algorithm in 7 seconds. It was ~~as~~ shown in Fig. 2b .

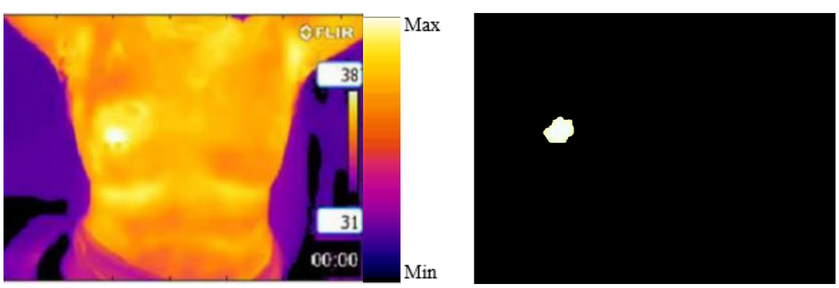


(a) Original image (b) Extracted the inflamed site

Fig. 2- Thermographic image of an inflammatory carcinoma patient (case 1) [16]

Case 2: Breast cancer [24]

Thermogram of a 58 years old female having right breast cancer (sub-areolar region) was presented. Breast cancer was confirmed by Fine-Needle Aspiration Cytology (FNAC). Using thermography, malignancy was accurately detected. Her thermographic image iwas shown in Fig. 3a. The tumor or the hottest region extracted by lazy snapping algorithm in 10 seconds and ~~was~~ presented in Fig. 3b.

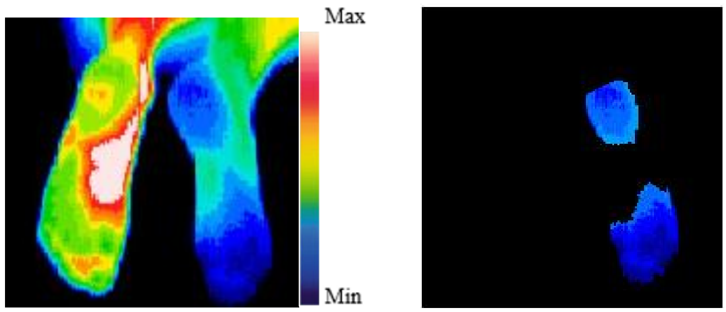


(a) Original image (b) Extracted the tumorous area

Fig. 3- Thermographic image of a breast cancer patient (case 2) [24]

Case 3: CRPS in foot [25]

A case with complex regional pain syndrome (CRPS) right foot was evaluated. Significant elevation in sympathetic motor tone right foot indicated 3.7°c colder than left foot. Also a cold stress test was positive. After a fractured calcaneum 18 months previously, CRPS experienced in the right foot. At first, diagnosis of CRPS was failed to be diagnosed since nuclear imaging missed CRPS. Thermography was able to identify CRPS. The coldest regions or the CRPS right foot areas extracted by Lazy snapping algorithm in 25 seconds and ~~was~~ demonstrated in Fig 4b.



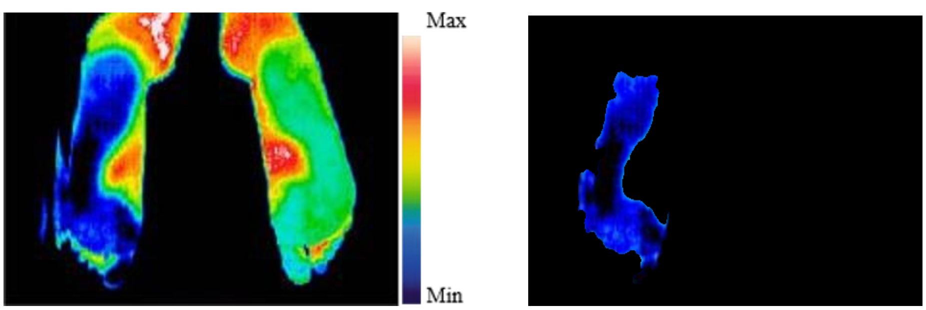
(a) Original image (b) Extracted the coldest region

Fig. 4- Thermographic image of a complex regional pain syndrome right foot case

(case 3) [25]

Case 4: Ischemic diabetic foot [26]

Thermogram of an ischemic diabetic foot was depicted in Fig. 5a. A lack of sufficient arterial blood flow from the heart to the foot was related to the ischemic foot. Cold skin temperature was related to this disease. It can be considered as an early sign of pre ulceration in ischemic foot to be detected in plantar thermograms. Routine thermographic imaging of his plantar feet led to diagnosis of the coldness. It helped him to be aware of the risk of ulceration in his left foot. The coldest region or the abnormal region of his left foot was extracted by lazy snapping algorithm in 8 seconds and ~~as~~ presented in Fig. 5b.

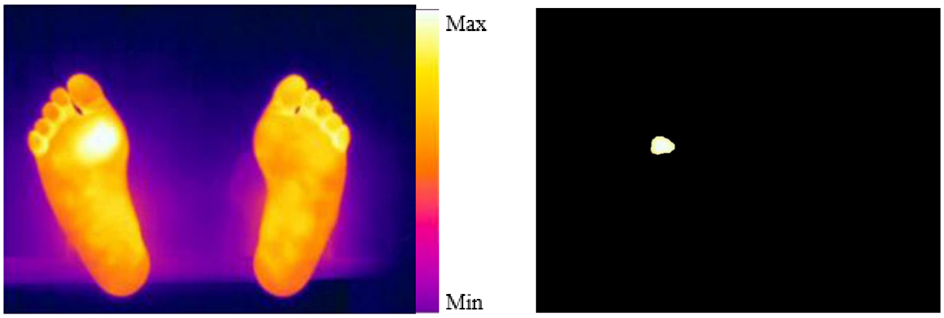


(a) Original image (b) Extracted the coldest region

Fig. 5- Thermographic image of an ischemic diabetic foot patient (case 4) [26]

Case 5: Diabetic neuropathy [10]

Thermogram of a male with diabetic neuropathy was demonstrated in Fig 6a. Hotness can be a sign of pre-ulceration of neuropathic foot in diabetic patients. His routine thermographic imaging led to identify the location of possible future right plantar ulcer. The hottest region or the region with high potential for ulceration extracted by lazy snapping algorithm in 15 seconds and ~~was~~ indicated in Fig.6b.

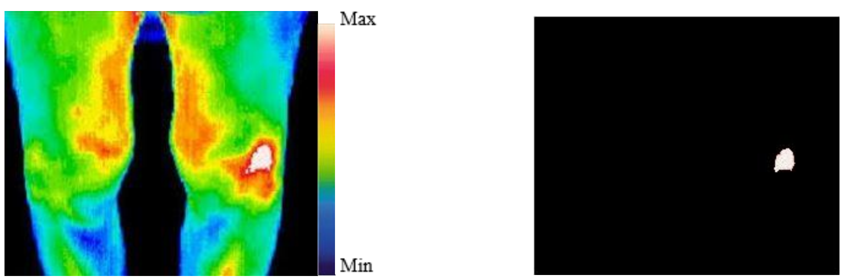


(a) Original image (b) Extracted the region with pre-ulceration

Fig. 6- Thermographic image of a subject with diabetic neuropathy (case 5) [10]

Case 6: Arthritic disorder [27]

Arthritic disorders generally appear as hot regions, since the affected sites are usually inflamed. Thermographic image of an arthritic disorders patient with synovitis local inflammation in Osteoarthritis (OA) was shown in Fig. 7a. He experienced OA flares (night pain, morning stiffness, usually exhibit in parallel joint effusion, as is seen in classical inflammatory arthropathies such as rheumatoid arthritis (RA)).The affected area was extracted by lazy snapping algorithm in 10 seconds and ~~as~~ revealed in Fig. 7b.

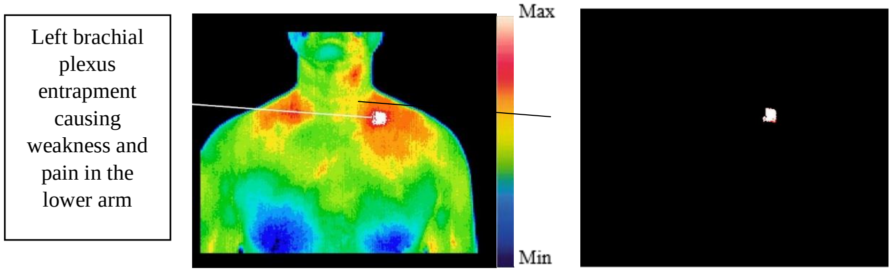


(a) Original image (b) Extracted the affected area

Fig. 7- Thermographic image of an arthritic disorders patient (case 6) [27]

Case 7: Brachial plexus injury [28]

Thermal image of a patient with brachial plexus injury was reviewed in Fig 8a. The patient was complaining about weakness and pain in his lower arm. The brachial plexus is a group of nerves that move from the spinal cord in the neck and go into the arm. The muscles of the shoulder, elbow, wrist and hand are controlled by these nerves. Feeling in the arm is also provided by these nerves. Injury of brachial plexus caused pain that shows up in thermograms as hyperthermia or hot spot region. The location of pain was captured in 12 seconds and shown in Fig 8b.

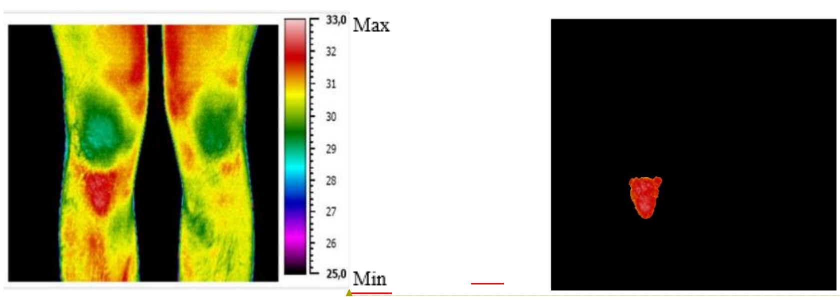


(a) Original image (b) Extracted the pain location

Fig.8- Thermographic image of a patient with brachial plexus injury (case 7) [28]

Case 8: Enthesopathy of the ligamentum patellae [29]

Happening of overuse injuries such as patellae tendinopathy is usually related to alpine skiing. It is indicated by swelling, pain and tenderness above the tibial tuberosity. This regional complication appears as hot spots in thermogrphic images. Excessive jumps lead to mechanical strain and overuse of the patella tendon that are commonly involved in the preseason training program. Thermographic image of the anterior aspect of the knees was presented in Fig. 9a. Enthesopathy of the ligamentum patellae disturbing the right knee was observable. The corresponded location of injury (patellae tendinopathy) was revealed in Fig. 9b. and the time taken was 10 seconds.



(a) Original image (b) Patellar tendinopathy injury

Fig.9- Thermographic image of the anterior aspect of the knees (case 8) [29]

Case 9: Abdomen kidney infection [30]

This patient presented with low back pain and no thermal diagnosis in her back thermographic image, however her abdomen thermographic image suggests a clear warm area over the right kidney that imply point pain to the back. Following tests indicated a kidney infection. Her thermogram can be seen in Fig. 10a and the inflamed site extracted by lazy snapping algorithm in Fig. 10b.. The time taken was 7 seconds.

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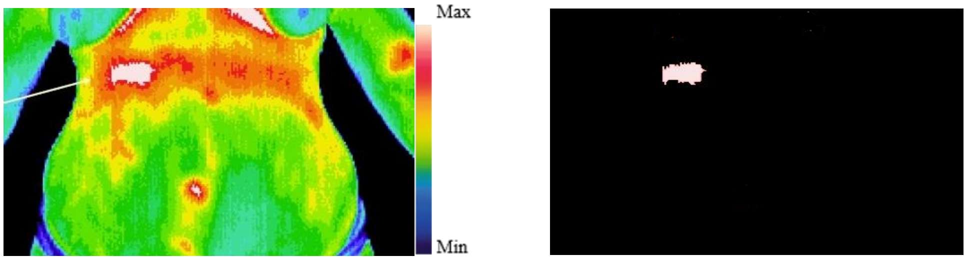
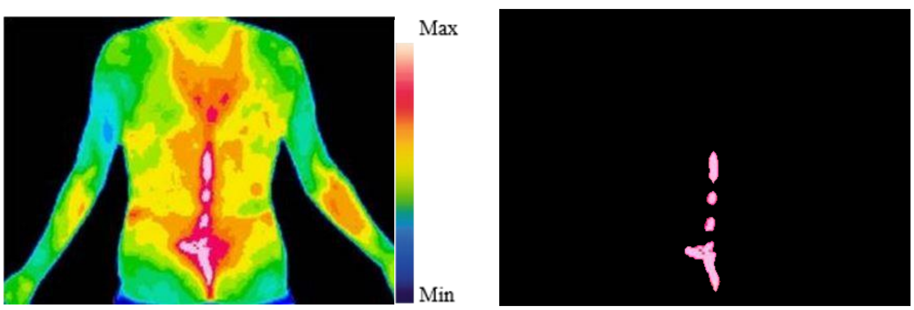


(a) Original image (b) Extracted the infected site

Fig.10- Thermographic image of a patient with lower back pain with no thermal diagnosis but an infection in her right kidney (case 9) [30]

Case 10: Lower back pain [31]

Lower back infrared image of one patient was included in Fig. 11a and the corresponded location of her lower back pain in Fig. 11b. The time taken to extract the region was 30 seconds.

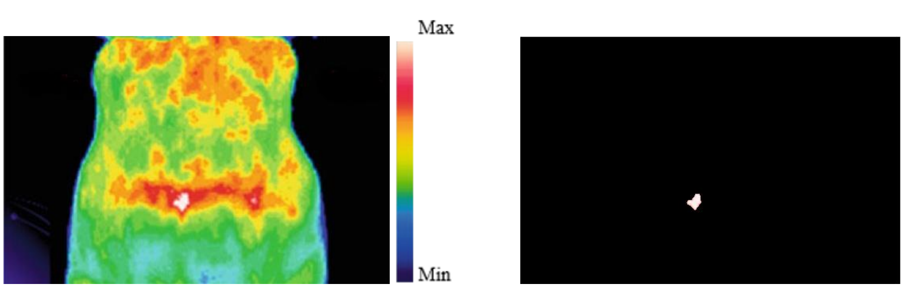


(a) Original image (b) Extracted location of pain

Fig.11- Thermographic image of a patient with lower back pain (case 10) [31]

Case 11: Active Crohn's Colitis [32]

A thermal image of a female patient with active Crohn's colitis was demonstrated in Fig. 12a. The location of her pain was extracted in 15 seconds and shown in Fig. 12b.

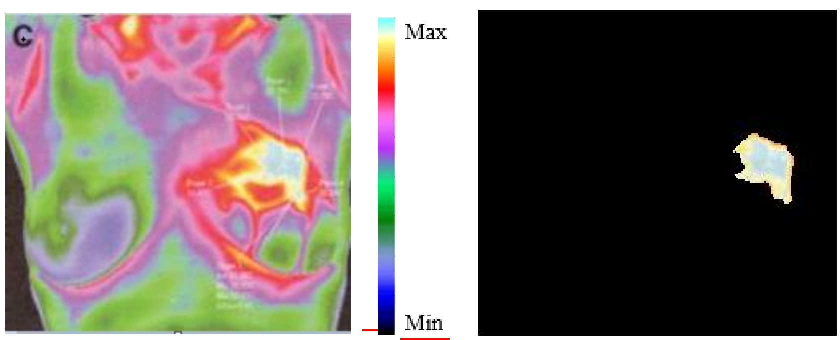


(a) Original image (b) Extracted location of pain

Fig.12- Thermographic image of the abdomen of a patient with Active Crohn's Colitis (case 11) [32]

Case 12: Advanced cancer in the left breast [33]

Thermogram of a patient with an advanced cancer in her left breast was shown in Fig. 12a. The extracted tumor region was demonstrated in Fig 12b and the time taken was 20 seconds. As we can see, segmentation was not done properly. Sometimes small areas with narrow and sharp edges cannot be extracted properly. It can be considered as a limitation for using lazy snapping to extract suspicious areas in body thermograms.



(a) Original image (b) Extracted location of tumor

Fig.12- Thermographic image of a patient with an advanced cancer in her breast (case 12) [33]

As we observe, the inflamed and tumor regions successfully were extracted in the inflammatory carcinoma and the breast cancer cases respectively. In addition, CRPS right foot areas and the coldest regions representing areas of high risk of foot ulceration were captured completely in the CRPS in foot case and the ischemic diabetic foot case respectively. The hot regions representing high potential region for ulceration and the inflamed region were properly extracted in the diabetic neuropathy case and the arthritic disorder case respectively. The injured area associated with pain was captured successfully in brachial plexus injury case while the patellar tendinopathy injured area in enthesopathy of the ligamentum patellae case. The inflamed site related to the kidney infection as well as the location of back pain were obtained properly in the abdomen kidney infection case and the back pain case respectively. It worth noting that implementing the algorithm was fast enough to be considered as an instant visual feedback. The time taken varied from 7 to 30 seconds for each of these ten cases. The authors, in the previous studies [16, 17, 18, 34, 35], applied different algorithms such as K means, fuzzy c means, level set and mean shift algorithms to segment breast thermograms. However, lazy snapping was more user-friendly and could provide instant visual feedback. In this study, our data collection included 15 breast thermograms, 25 feet plantar thermal images and 15 thermal images of patients with pain. Lazy snapping worked perfectly well for 39 cases. Hence we concluded that lazy snapping had a sensitivity of 0.70. However, we obtained low accuracy for cases that involves small suspicious regions with narrow and sharp edges. It can be considered as a disadvantage of applying algorithm in our study.

Conclusion:

In this study, lazy snapping algorithm was applied to extract the suspicious areas, inflamed sites, and affected regions probable for feet ulcerations in thermographic images of patients; for breast cancer, patients with pain, sport injured patients and diabetic people respectively. Twelve cases were presented to show the results. The time taken to extract the breast tumor regions in cases 1 and 2 were 7 and 10 seconds respectively. Moreover, extracting the regions susceptible for ulceration in diabetic patients in cases 3, 4 and 5 took 25, 8, and 15 seconds respectively as well as acquiring the inflamed regions in cases 6, 7, 8, took 10, 12, 10 seconds respectively. Besides, tThe he time taken to see obtain locations of the pain in cases 9 and 10 were 7 and 30 seconds and for cases 11 and 12 were 15 and 20 seconds respectively. the results of these twelve presented cases varied from 7 to 30 seconds. In addition to being quick, the algorithm was very user-friendly. It worth mentioning that comparing to the other methods used by the authors such as K means, fuzzy c means, level set and mean shift algorithms for segmentation, lazy snapping was much faster and it provided the results for physicians in real time readily. The author believes that lazy snapping algorithm has potential be applied to extract the hottest or coldest regions in body thermographic images quickly with easy detailed adjustment.

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