Detection of Unstable Burst Fractures of Lumbar spine based on a New Thermography Technique

Abstract

Background: The burst fractures of the vertebrae include about 15% of spinal column injuries, and the most common location is in the lumbar back area. The diagnosis of fracture types and associated injuries is usually done by using simple radiography, CT scan, and MRI. In this research, we tried to present a new method for fracture detection with the thermographic images.

Methods: The present study was a preliminary study, which was conducted on a set of thermal images obtained from a Clinical Center in California. The diagnosis (detection) of unstable burst fractures of the lumbar spinal column was performed based on the thermal pattern using the Fuzzy C-Means (FCM) clustering method and recursive connected components algorithm. In this study, the procedure was validated and confirmed by examinations and evaluation previously made by an orthopedic surgeon on the same patients.

Results: After applying the preprocessing steps and FCM clustering on the image, the clusters belonging to the lumbar spine, which center was at the first and second places of the clusters centers matrix, were gathered together. Then, the unstable lumbar spinal burst fractures were diagnosed based on the components labeling technique. From the 130 thermographic images, 93 showed fracture and in 33 no fracture was seen. This confirms with the CT scan images, and shows 95% accuracy.

Conclusion: The method presented in this article is a non-invasive and cost-effective approach for the diagnosis of unstable burst fractures of lumbar spinal column. The techniques and tips derived empirically, based on the scientific principles of this research, can help the physicians to quickly diagnose the burst fractures of lumbar spinal column based on the analysis of thermal images.

Keywords: Thermography, Spinal Column, Fracture, Connected Components, Radiation

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Introduction

The burst fractures of the vertebrae include about 15% of spinal column injuries, and most common location is in the lumbar area\(^1,2\). The usual method of diagnosis of fracture type and associated injuries is by using simple radiography, CT scan, and MRI images. However, these methods have many limitations such as the risk of radiation and high costs. These methods are widely used in clinical areas as precise and useful tools, which are very time-consuming and costly. In the medical field, new technologies are not only used to improve the quality of life of patients but also have some applications for the healthy people. However, each method has unique advantages and disadvantages, many of which will have a compromise between efficiency and accuracy versus ease of use and cost considerations. In this research, we tried to provide a new method for fracture detection in the thermographic images. Infrared technology is one of the technologies with applications in both medical and biological fields. The Infrared Thermography (IRT) has been so far successfully employed to diagnose breast cancer, diabetes, etc.\(^3\). However, no research has been done on diagnosis of lumbar spine fractures by IRT. We used the IRT in this paper for the first time as a non-invasive and cost-effective method to detect the burst fractures of the lumbar spinal column. In the past, the infrared (IR) imaging had not been widely recognized in the medicine due to the premature use of the technology\(^4\).
A few decades ago, when the accuracy of measuring the temperature and spatial resolution were inadequate and complex, the image processing tools were not available. This situation was dramatically changed in the late 1990s-2000s. The advances occurred in IR tools, implementation of digital image processing algorithms and dynamic IR imaging provided the possibility of spatial analysis for the scientists and also enabled them to evaluate the temporal thermal behavior of the skin\textsuperscript{(5)}. It also provided the context for progress in this area. The uses of this kind of imaging in medicine are rapidly increasing. Although, in some previous studies, some researchers have succeeded to observe the thermal continuity in the lumbar spine in the burst fractures of the lumbar spinal column; but so far, no research has been done on the automatic detection of this type of fracture by IRT. The infrared imaging is a non-invasive imaging method that is used as a diagnostic tool. The main source of infrared rays is the heat coming from a variety of bodies whose temperatures are greater than absolute zero. Therefore, the thermogram provides the distribution of heat in the body from a patient\textsuperscript{(6)}. The thermal camera is used to record thermal images. These cameras have many advantages such as lower cost than other methods, are non-invasive with no direct contact, no radiation, low volume, portable, and usable at any angle\textsuperscript{(7,8)}. Thus, due to the limitations of access to the specialized fast services to diagnose the diseases, in the present study, we used the Thermography (IRT) as an economical and non-invasive approach to detect this type of fracture to help the physicians diagnose the fractures faster by analyzing the thermal images.

\section*{Methods}

The present study is a preliminary report. All techniques and processes made on the images used in this article were performed by the authors in 2016 at the Hakim Sabzevari University. The proposed algorithm automatically detects the unstable burst fractures of the lumbar spine based on the new and non-invasive method of thermography and according to the images processing techniques that the system automatically analyzes without the need for analysis by a physician. To verify the validity of the probability of fracture in the resulting images that had been already examined clinically, we evaluated the system performance on a set of thermal images taken from individuals. These were 130 thermographic images, taken on cases with the clinical diagnosis of lumbar spine fractures at a clinical facility in California. These images were used for automatic detection of fractures with complete consent of the patients at the center.

At the center, thermo-graphical imaging was initially done on the patient. Then, based on the CT scans taken from the patients referred to this facility, a specialist physician at this clinical center detected the presence or absence of fractures in these individuals. But in the clinical diagnosis made at the center, there was the problem of incorrect diagnosis at the thermal continuity in the spinal column area, resulting in high number of false fracture diagnosis in the area. The usual thermal images are displayed by color pixels. Sometimes, depending on the images and in the presence of a limited number of pixels in a thermal and color range in the spine region, the physician will not able to correctly identify the thermal continuity or non-continuity in the image. Therefore, by applying image processing techniques, we tried, in this research, to automatically detect the spinal fractures in the thermographic images to minimize the diagnostic errors. In this paper, automatic detection of fracture was done based on the thermal pattern by using the FCM clustering method and the recursive connected components algorithm on the thermal images obtained from the infrared camera implemented by MATLAB software.
The calculations were made with a precision above 95%.

The proposed method consists of several steps as follows. An example of a normal thermal image (thermal continuum in the lumbar spine) is shown in Fig. 1:

![Figure 1. Normal thermal image taken from a patient](image)

- **Preprocessing stage**

  Since the clustering algorithm employed in the proposed method (FCM), used to separate the clusters belonging to the lumbar spinal column, is very sensitive to noise, therefore, the images should have sufficient resolution and the boundaries between the color layers need to be well-defined and distinguishable from each other for the precision of separation. If the images are noisy, the separation of clusters belonging to the lumbar spine is not properly done by the clustering algorithm. Hence, the noise cancellation filters can be used to resolve this problem to improve the separability of the image edges, and thus, the performance of the clustering algorithm. Therefore, the first step in this method, which is considered as a preprocessing step, includes the stages to remove the image noise by the middle and middle filters and then sharpen the image by a high-boost filter after noise removal. The images of the preprocessing stages and the spine marked with the red rectangle in the lumbar region of the patient are indicated in Fig. 2.

![Figure 2. An input image which noise has been removed after applying the preprocessing steps.](image)

- **Image clustering**

  After performing the pre-processing steps, it is the time for image clustering stage by the fuzzy clustering algorithm (FCM). Therefore, a brief explanation of this clustering algorithm was given below.

  In 1969, Ruspini proposed the first clustering model with a fuzzy idea. In this method, the membership or belongingness rate of each data object to each cluster is determined by the membership matrix 

  \[ U = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{c1} & u_{c2} & \cdots & u_{cn} \end{bmatrix} \]

  where "c" is the number of clusters and "n" is the number of objects.

  **Detection of the clusters belonging to the spinal column**

  A digital image is a two-dimensional array of pixels, in which, each pixel has certain brightness or a color. Our proposed algorithm acts on the thermal images obtained from the infrared camera and is implemented by MATLAB software. In the software environment, a thermal image is recognized as a 3D array and in the RGB space. There are three numbers in the RGB space corresponding to each pixel, each of which shows the intensity of one of the three primary colors of red, green, and blue for the pixel. The numbers for R, G, and B for each pixel are in the range of [0-255] and the combination of different intensities of these three colors make all the required colors. Figure 2 shows the desired region of the thermal image in the RGB space with R, G, and B values for a portion of its pixels. Therefore, the region of the lumbar spine in the thermal image, marked as a red rectangle (Fig. 2), has certain values of R, G, and B. Our proposed algorithm intelligently considers a part of the intensity of the R, G, and B colors belonging to the spinal column (Fig. 3) and compares with the values of R, G, and B of the obtained clusters. Eventually, it considers the clusters containing those values of R, G, and B as the clusters belonging to the lumbar spine and puts its center at the first and second places of the matrix of the centers of the clusters (clusters 1 and 2) (Fig. 4).

  **Calculation of the cluster belonging to the spine**

  At this stage, the clusters containing the spine identified in the image should be combined to obtain the cluster belonging to the spine. Therefore, in the examined image, the clusters belonging to the lumbar spine with their centers located in the first and second places of the matrix of clusters’ centers (clusters 1 and 2) should be summed. The result of calculating the cluster belonging to the spine is indicated in Fig. 5.

  **Detection of unstable lumbar spinal burst fractures**

  At this stage, the component labeling technique was used to detect fractures in the spinal area. The recursive connected components algorithm is one of the components labeling methods. We used this algorithm in this part of the fracture detection. We first briefly explained how this algorithm is implemented.

  **Recursive connected components algorithm**

  This algorithm is implemented as follows:

  1. The image is scrolled to find a pixel 1 without a label and assign a new label of L to it. 2. In a backward pattern, a label L is assigned to all the neighbors 1 of that pixel. 3. If there is no pixel 1 without a label, the algorithm will be stopped. 4. Go to Step 1.

  After labeling the components, as described in this algorithm, a single tag (label) is assigned to all connected components in an image. Therefore, in the second step, to detect a fracture, if the number of segments specified in the image is greater than one, a fracture has occurred in the...
spine, and otherwise, there is no fracture. The steps of labeling and the number of constituents of the spine, which determines the result of this diagnostic step on the examined, are indicated in Figure 6.

Results

The result of FCM clustering on the image taken from the patient's back is indicated in Figure 4, including the lumbar spinal column. As can be seen, the number of clusters in the implementation of the FCM algorithm to detect the presence of fractures was considered to be 10 clusters, and the center of clusters, including the lumbar spine, was considered in the first and second places of the matrix of clusters' centers (clusters 1 and 2).

![Figure 4. The result of the implementation of the FCM clustering algorithm applied to the examined area of the image](image)

The result of calculating the cluster belonging to the spine is specified in Fig. 5, which is the sum of the two clusters 1 and 2.

![Figure 5. The cluster belonging to the spine, which is the sum of the two clusters 1 and 2.](image)

The number of spinal cord segments obtained from the cluster belonging to the lumbar spine after the implementation of the labeling step is specified in Figure 6. Therefore, depending on the number of sections forming the spine, we can identify the presences of the fractures. The results from this diagnostic step on the image used in this article show the lumbar spine fracture for the affected person. In this study, out of 130 images, 98 showed fracture, and 32 images showed no fracture. These findings are in consistent with the CT scan results from patients (with a precision of 95%).

Discussion

The results of the analysis performed in this study suggested that a temperature uniformity is found in the lumbar spinal area in a healthy person. Thus, when a temperature dissociation is observed in this area, it can be considered as one of the most reasonable cause as a fracture in the spinal area. In this research, which has been done for the first time, we used the image processing techniques to detect this kind of fracture. This was a preliminary study. All techniques and processes made on the
images used in this article were performed by the author and colleagues of this research in 2016 at Hakim Sabzevari University. To verify the validity of the proposed algorithm, automatic detection of unstable burst fractures of the lumbar spine with image processing techniques was assessed on a set of thermal images taken from individuals.130 images, which have been examined for clinical diagnosis of lumbar spine fractures based on the thermography method at a clinical facility in California were tested. Although in recent years, a number of researchers have succeeded to prove that the infrared thermography is a good technique for diagnosing fractures and spinal cord injuries[14], the diagnoses had been done only clinically. However, after the images were obtained by the thermal camera, the images should be analyzed, and meanwhile, there is a possibility of a false diagnosis. This is one of the main and most important disadvantages of previous approaches compared to the method presented in this article.

The absence of harmful radiation effect is one of the important advantages of the method, while the failure to obtain suitable thermal images due to the patients' thermal imbalance in the body for various reasons such as stress is one of the weaknesses of this method[15]. Therefore, it is recommended that the patient be kept relaxed a few minutes before the thermal imaging, and put his hands in cold water to reach the body's thermal balance. Hence, although we managed in this study to detect unstable lumbar spine fractures automatically using the infrared imaging, however, further research in measuring the thermograms is needed to develop an advance this diagnostic approach with even less false positive results in future.

This method is effective and applicable at any time after the occurrence of the fracture (before fracture repair), but it does not indicate the time of fracture. It also has a higher diagnosis capability in more advanced, comminuted or multilevel fractures with a lower probability of error.

**Conclusion**

In this research, we detected the spinal fractures using the thermographic (IRT) method using image processing techniques, which has the advantages like being non-invasive, and cost-effectiveness. Based on the research results, this method can be used as a suitable alternative for fracture diagnosis instead of the other conventional methods.

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References