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Computer aided erosions and osteophytes detection based on hand radiographs

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ABSTRACT

In this paper we present a computer system to detect erosions and osteophytes from hand radiographs, the most common symptoms of rheumatic diseases. The designed, implemented and verified algorithm uses techniques of image processing, image analysis and pattern recognition. In the stages of image processing and image analysis, the locations of metacarpal bones, the outlines of finger bones, the locations and outlines of joints and finally the borders of joint surfaces are identified. In the pattern recognition stage, a shape description language is used for each border of the joint surface to detect the locations of erosions and osteophytes on hand radiographs. The presented algorithm expands on those known from the literature, because besides erosions it also detects osteophytes. Moreover, in contrast to previous systems, it analyses proximal interphalangeal joints and distal interphalangeal joints. The obtained results are satisfactory and very promising. The joints are successfully located in 98.3% of cases. The average mean distance between the borders pointed out by radiologists and obtained from the system varies between 0.094 mm and 0.157 mm, while the sensitivity and the specificity equal around 70% in most of the cases. Therefore, it can become a basis for the diagnosis of certain diseases.

1. Introduction

Within the scope of rheumatology and diagnostic radiology, it is essential to distinguish between inflammatory and non-inflammatory diseases. To give a diagnosis at an early stage of a disease, radiographs are taken of the patient's hands and the symmetric joints are analysed. The analysis is conducted in order to detect the lesions, which are taken into consideration during diagnosis, together with other tests (e.g. blood tests). However, due to the number of hand joints, such a standard analysis is exceedingly complicated and time consuming. To minimize the time spent on this analysis and to make a radiograph examination more frequent and precise, this process should be automated.

In this paper we present a computer system to detect erosions and osteophytes from hand radiographs, the most common symptoms of rheumatic diseases. The designed, implemented and verified algorithm uses the techniques of image processing, image analysis and pattern recognition. In the stages of image processing and image analysis, the locations of metacarpal bones, the outlines of finger bones, the locations and outlines of joints and finally the borders of joint surfaces are identified. In the pattern recognition stage, a shape description language is used for each border of the joint surface to detect the locations of erosions and osteophytes on hand radiographs.

The main achievements described in this paper:

- introducing a new algorithm of local segmentation based on a region growing (see Section 4.1.2),
- defining a new shape description language for syntactic pattern recognition (see Section 4.3.2),
- presenting a multi-stage algorithm, which expands on those created so far (see Sections 4 and 5),
- designing, implementing and testing an automatic computer system which detects erosions and osteophytes (the system operator has to only load the image and mark the area of the analysis – see Section 4).

Detecting osteophytes is innovatory due to the fact that in the research results published so far, the borders of joint surfaces were used only for detecting joint space narrowing and erosions.

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The test set consists of the left and right hand radiographs of 60 patients, taken in the anterior posterior position. Among those, 20 are healthy, 20 suffer from degenerative diseases and 20 suffer from inflammatory diseases. Such a test set was used to conduct numerous analyses whose results were investigated.

This paper is organized in the following manner. In Section 2, the medical basis of the topic is outlined. In Section 3, attempts to detecting joint space narrowing and erosions using the existing methods are very briefly presented. Detecting erosions and osteophytes using a special algorithm is presented in Section 4. The obtained results and the discussion are presented in Sections 5 and 6, respectively.

2. Some data concerning the medical aspects of the paper

Despite the fact that magnetic resonance imaging (MRI) shows the greatest sensitivity for detecting and monitoring bone erosions [16], conventional or digital radiography of the hand is the most commonly used imaging method in diagnosis, as well as monitoring disease progression and the treatment response in case of the patients with rheumatic musculoskeletal diseases [3]. This is due to the fact that radiography is widely available, inexpensive and easy to perform, as well as valuable in differential diagnosis [16].

In general, there are two groups of rheumatic musculoskeletal diseases. The first group is described as inflammatory disorders, with rheumatoid arthritis being the most prevalent (from 0.5% to 1% suffers from inflammatory diseases). The second group is known as non-inflammatory disorders and includes the degenerative diseases of the joints, e.g. osteoarthritis, the most prevalent one (from 11% to 14% of the population suffers from rheumatic diseases). There are several radiographic lesions [3] corresponding to these two groups. The most important ones among them are erosions and osteophytes (see Fig. 1a and b). The occurrence of those lesions in specific places may indicate, together with the other tests (e.g. blood tests), on the particular type of disease.

There are three joints of interest in the cases of rheumatoid arthritis and osteoarthritis (see Fig. 2): metacarpophalangeal joints (MCP, the joints between the metacarpal bones and the proximal phalanxes), proximal interphalangeal joints (PIP, the joints between the proximal and middle phalanxes) and distal interphalangeal joints (DIP, the joints between the middle and distal phalanxes). MCP joints are condyloid joints, whereas PIP and DIP joints are hinge joints. The differences in their anatomy result in differences on radiographs, therefore the analyses in both cases has to differ.

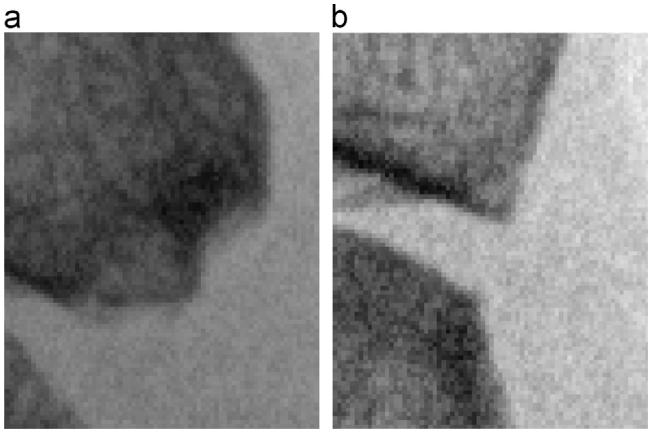

Fig. 1. An upper surface of metacarpophalangeal joint with erosion (a) and osteophyte (b).

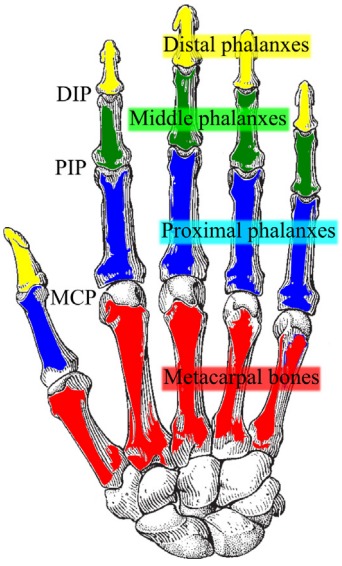

Fig. 2. Hand anatomy.

3. Detecting joint space narrowing and erosions using the existing methods

There are a number of papers concerning the topic of computer aided rheumatoid diagnosis based on hand radiographs. Some of them focus on segmentation of the hand radiographs – see [18,23,24,28,30,36,41]. Others relate to identifying the joint surface borders and detecting joint space narrowing – see [10,11,34–36,38,39,25]. However, according to Peloschek et al. [32], only a few of them relate to detecting erosions – see [26,27].

The segmentation of selected bones can be carried out using various methods, such as the active contour model [18], the active appearance model [23,24], the analysis of the profile plots [30,41] and random Gibbs fields [36]. Full segmentation is obtained by Lehmann et al. [28] using the watershed method.

One of the approaches for identifying the borders of joint surfaces and detecting joint space narrowing involves the regions of interest (ROI) which are set by the system operator [10,11,34,35,38,39] or are computed automatically [25,36]. Each ROI is processed with the Sobel filter and then analysed to obtain two approximately parallel borders of the upper and the lower joint surfaces as well as the corresponding joint space width. Such analyses usually concern only the middle fragments of borders. The lengths of such fragments are proportional to the average width of the joint surface, whilst the joint space width is given as the mean distance between the points of the upper and the lower fragments [25]. In another approach proposed by Sharp et al. [38,39], the system operator marks 5 points between the upper and the lower surfaces. Based on those, the 13 points on the upper and the lower surfaces are determined and the 2 corresponding geometric functions are approximated. The joint space width corresponds to the mean distance between the plots of those two functions.

An algorithm for detecting erosions was proposed in Langs et al., [26,27]. The initial estimates of the joint locations in this algorithm are obtained by local linear mappings based on texture features. The bone borders are delineated by the active shape models comprised of the statistical models of bone shape and local texture. These models are refined by snakes which increase the accuracy and allow for the fitting of pathological deviations from the training population. The algorithm then detects erosions on the bone border using a texture analysis of the rectangular regions.

In this paper, the algorithm for erosions and osteophytes detection in MCP, PIP and DIP joints on hand radiographs is proposed. It is needed