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Automatic analysis of the trunk thermal images from healthy subjects and patients with faulty posture

Robert Koprowski *

Department of Biomedical Computer Systems, University of Silesia, Faculty of Computer Science and Materials Science, Institute of Computer Science, ul. Będzińska 39, Sosnowiec 41-200, Poland

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ABSTRACT

Background: This paper presents an automatic method for assessing temperature distribution on the patient's back using thermal imaging. It discusses the advantages and disadvantages of thermal imaging and presents an algorithm for image analysis and processing that runs automatically and reproducibly.
Method: The proposed new method of image analysis relates to automatic and reproducible analysis of temperature distribution on the patient's back. It includes the following steps: (1) detection of the external contours of the human body, (2) identification and recognition of the position of the arms, hips and shoulders, (3) application of a mesh having a fixed number of fields (which automatically adapts to the size of the patient's back), (4) analysis of the paraspinal muscles. These steps are preceded by image pre-processing.
Results: Based on a thermal image, this new fully automated algorithm enables to: (1) evaluate temperature distribution in the paraspinal area; (2) pre-assess the degree of lateral spinal curvature in screening, and (3) evaluate anomalies (deviations from the norm) in temperature distribution. The algorithm was practically implemented in Matlab Image Processing Toolbox.

1. Introduction

Thermal imaging is a non-invasive, non-contact and reproducible method for assessing temperature distribution of all objects with temperature greater than absolute zero. Owing to these features, it is widely used both in technology, industry and medicine. The use of thermovision in medicine involves assessing temperature distribution of the analysed body area. This is usually a quantitative or qualitative assessment but only in areas indicated by the operator. Areas having the same temperature and optionally the same temperature gradient are evaluated qualitatively. On this basis it is possible to evaluate different types of diseases: both arthritis and allergic reactions or the quality of beauty treatments. The growing popularity of thermal imaging has been rapidly inhibited in recent years. The reason for this is very high sensitivity of thermal methods to measurement errors. The most important of these errors include:

- the impact of hot meals consumed immediately before the test,
- the impact of other undisclosed diseases, especially feverishness and local dermatitis,
- the impact of thermal adaptation of the room,
- the impact of other external sources of thermal radiation,
- the impact of foreign body interference in the place subjected to imaging – e.g. touching this place with the patient's hand prior to imaging,
- the impact of the patient's body thermoregulation (psychological condition, a big meal eaten a few minutes before the test).

Elimination of the effect of these errors on the measurement results can only be provided by a thorough medical history and appropriate preparation of the patient before the test. This is not always possible when the measurements are being taken. However, errors likely to be made in the thermal imaging diagnosis can be very large, for example, false positive in detecting breast cancer [1]. An alternative to these static thermal tests are dynamic methods of temperature distribution evaluation. These methods involve recording a sequence of thermal images and quantitative analysis of the time constant temperature change rate for each analysed area of the patient's body [2–4]. However, they are based on the assumption that the human body model can be estimated with an inertial system of the first or second row. This assumption is not always correct and does not include all the processes in the human body. Therefore in the present paper the focus is on static thermal measurements.

The problem of faulty posture is a broad, still popular area of knowledge in the field of biomechanics, medicine and ergonomics [5–10]. Currently, there are many well-known techniques for

* Tel.: +48 323689741.
E-mail address: robert.koprowski@us.edu.pl

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assessing postural defects ranging from three-dimensional imaging of the human body to Moire fringes [11]. In the area of spinal curvature analysis, one of the most popular methods is the X-ray examination or CT scan [12–14]. In either case the patient consumes a certain amount of radiation. Lateral spinal curvatures are mainly measured using one of Cobb, Ferguson or Gruca methods [15]. The amount of radiation is smaller in the case of screening and bigger for the treatment of lateral spinal curvatures where the X-ray examination is performed every week or even more often.

The known literature on the different methods of faulty posture assessment can be divided taking into account the criterion of accuracy. The methods of three-dimensional assessment of faulty posture use a set of 2, 3 or 4 cameras. These cameras usually work in visible light. For example, in the study [16], a 3D scanner was used in 23 year-old volunteer patients. 28 measurements divided into three tests were performed. Variations were observed for the three different tests. The highest error value was 49.91 mm. In paper [17], particular attention was paid to the differences between sexes (men and women) in terms of movement in the joints visible in 3D imaging. For flexion and abduction and with regard to the scapular kinematic, external rotation was far greater for women than men. The differences were of at least 5° at 120° of humeral elevation. An interesting study in the field of 3D imaging of faulty posture and patients' posture was presented in publication [18]. A model of the human body was obtained on the basis of the image acquired in visible light from two typical cameras and a classifier based on the support vector machine (SVM). Another paper, [19], shows the use of 3D modelling for motion analysis of patients using the SVM. Similar equipment, 2 or 3 cameras, was also used in other works related to the assessment and diagnosis of faulty posture, both statically and in motion [20–23].

The Moire fringe method has been known since 1966, and one of the most popular areas where it is used to this day is the measurement of faulty posture and scoliosis [24]. One of the studies in which the greatest number of patients (9804 girls and 8699 boys aged 4 to 18 years) was analysed using this method is described in [25]. However, the imaging area concerned only the foot – changes in its size during patients' growth. In publication [26], the forward bending test, widely used in scoliosis screening, related to high false-positive rates. For 60 analysed patients there was a significant number of false-positive results for the spinal curvature angle to a maximum of 10°. In contrast, in paper [27] the funnel chest was measured. The authors of publication [28] presented an application providing the accuracy of 1 cm when measuring posture with the use of the Moire fringes.

The use of X-ray radiation in the diagnosis of faulty posture and mainly scoliosis is widely described in literature, both in terms of its common use and risks. For example, in the study [29] 31 patients were analysed. It was suggested that cancer incidence is high in subjects with scoliosis who are relatively more frequently subjected to X-ray for diagnosis and follow-up. X-ray is a type of ionising radiation and results in the formation of oxygen free radicals which are capable of causing damage to DNA, thus altered gene expression and mutation. Similar works [30–34] relate to the assessment of the effects of harmful X-radiation on patients, in particular, those with faulty posture.

Therefore there is a justified need to use other techniques to assess the correct posture, postural defects and spinal curvature.

Automatic thermal imaging methods for measuring faulty posture are known from the literature [15,35–42]. The possibilities of the known thermal image analysis and processing methods applied in the analysis of faulty posture and lateral spinal curvatures are summarised in Table 1.

As outlined in the Table 1, the presented methods do not allow the algorithm to work fully automatically – manual adjustment and selection of a specific area by the operator are necessary. The manual selection of reference points and/or manual indication of areas are not reproducible. A group of well-known automatic methods can indeed enable automatic and reproducible work. However, the analysed area does not apply simultaneously to the analysis of the patient's arms and back. In addition, the known methods do not enable to evaluate the degree of temperature distribution asymmetry and link it to a postural defect (lateral spinal curvature). A method devoid of these drawbacks is described in the following sections.

Table 1
Summary of the possibilities of the known thermal image analysis and processing methods used in the analysis of faulty posture and lateral spinal curvatures.

Feature	Skolimowski et al. [15]	Koprowski and Wróbel [35]	Miyake et al. [38]	Koprowski and Wróbel [39]
Automatic measurement	No	Yes	No	Yes
Impact of patient size	Yes	Yes	Yes	No
Quantitative analysis of results	No	Yes	Yes	Yes
Programming language	none	Matlab	none	Matlab

2. Material

Image analysis was performed on the previously (retrospectively) acquired thermal images. They included images available in the repository (Open-Access Medical Image Repositories) and artificially generated ones (proprietary software). A variety of sources and origins of the analysed thermal images was necessary to verify the accuracy of the proposed image analysis and processing method. Patients (or their caregivers in the case of children) aged from 10 to 50 gave voluntary consent to testing, and measurements were performed during routine medical examinations. In total, more than 1000 images were acquired in infrared light. No measurements or tests were performed on patients for the purposes of this study. Thermal images related to healthy subjects, patients with faulty posture (the angle of spinal curvature in the frontal plane according to Cobb $\leq 10°$) and lateral spinal curvature (curvature angle according to Cobb $> 10°$) in the following proportion: 30%, 20% and 50% respectively. Before testing, all patients stayed in an air-conditioned room (thermal comfort of 21 °C), stripped to the waist, for a minimum of 20 min. After this time, measurements using FLIR SC5200 infrared camera at a distance of 2.0 m from the patients, perpendicular to their back, were performed. The camera operates in the range of 3–5 μm and provides images with a resolution $M \times N = 320 \times 240$ pixels and a minimum temperature resolution of 0.1 °C. In the case of other infrared cameras, the image resolution was automatically adjusted to 320×240 pixels. Positioning the patient during the test is shown in Fig. 1 a.

3. Method

The proposed, new method of image analysis relates to automatic and reproducible analysis of temperature distribution on the patient's back. It includes the following steps: (1) detection of the external contours of the human body, (2) identification and recognition of the position of the arms, hips and shoulders, (3) application of a mesh having a fixed number of fields (which automatically adapts to the size of the patient's back), (4) analysis of the paraspinal muscles. These steps are preceded by image preprocessing.