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Method to model the spinal column shape

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Abstract. Correct evaluation of the spine is important in detecting the deficiencies that may occur at this level, especially in case of scoliosis. It is proposed a new method of acquiring the coordinates of the column in order to generate a model of it. A number of eight coordinates has been chosen to use, a big enough number to assure a true model of the spine and a wide area of possible mathematical approaches. The acquiring system consists of eight accelerometers, from which is collected the pitch angle. This angle, as the angle of inclination in the frontal plan is used to compute the pairs (x, y), considering known the distance between the sensors. The accuracy of the model is validated by comparison with images taken during the measurement.

1. Introduction

Spinal deformities occur frequently in children during the period of growth most of them not having a precise cause but can also occur in adult population, due to lack of physical activity and long-term sitting position [1, 2, 3]. Researches in this field are widely spread and continuously developing, as the current schemes of treatment are long-lasting, costly and not very effective.

In order to assess a spinal deformity it is necessary to evaluate the shape of the column. In this regard, the most commonly used method of investigation is the X-Ray image. However, due to its invasive nature and limitation in providing information, a wide range of alternative methods of investigation have developed during the last decades. The purpose of seeking for new methods of investigation is to assure a non-invasive character, the electronic storage of data and richer information.

The shape of the column and different parameters associated with posture can be obtained through different methods, among which the most common are raster stereography [4], ultrasonic mapping [5, 6], thermography, image processing [7, 8], mapping based on information provided by different sensors [9, 10]. The researches in the field of designing new methods to generate mathematical models of the spine are in progress, as none of the existing ones provides enough efficiency, accuracy and reliability.

The authors of the present paper propose a method of investigation based on the use of accelerometers, which provide data for computing a set of coordinates of the column and allow the generation of a mathematical model.

2. Equipment and processing of data

The method proposed to acquire data is based on the use of a set of accelerometers attached to the back of the patient (figure 1 a). The system consists of a set of 8 MEMS IMUs connected via their I²C bus to an I²C multiplexer and finally to a microcontroller board (figure 1 b) [11]. The accelerometers provide the angles relative to the vertical axis, within the frontal plan (pitch angles).



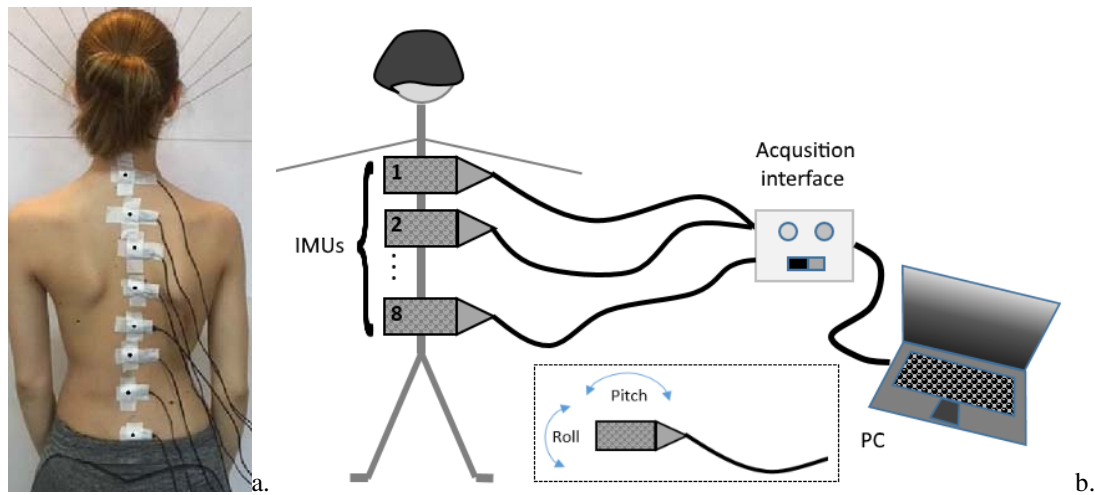


Figure 1. Scheme of the sensors applied on the column and acquisition system. [11]

The angles φ_i ($i=1 \dots 8$) and the distance l_i between the sensors (fig. 2) allow the computation of their coordinates (x_i, y_i):

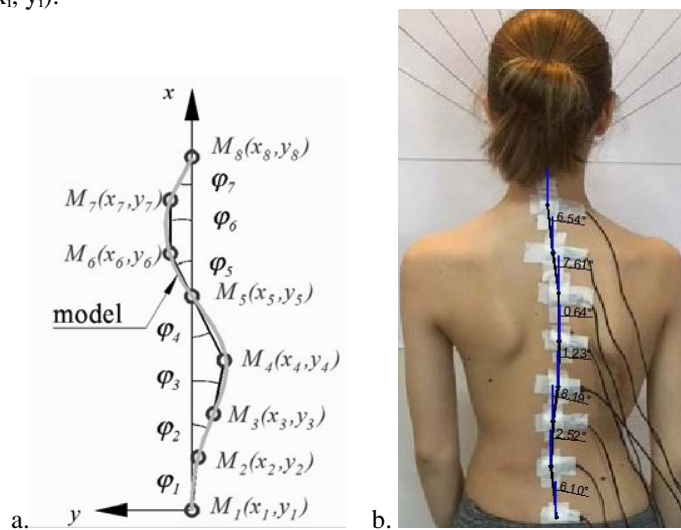


Figure 2. Points and associated parameters. a – theoretical model; b – illustrative example.

$$\begin{cases} x_{M1} = 0 \\ y_{M1} = 0 \\ x_{Mi+1} = x_{Mi} + l_i \cos \varphi_i & i = \overline{1,8} \\ y_{Mi+1} = y_{Mi} + l_i \sin \varphi_i & i = \overline{1,8} \end{cases} \quad (1)$$

The reference system attached to the application originates in the first point. The coordinates so obtained are used to get an approximation function, which was chosen to be a fifth degree polynomial. In order to further process the shape of the column it is necessary to validate the accuracy of the acquired data. For this purpose, during the measurement were taken photos of the patient with the sensors attached. The centers of the sensors are emphasized with black point markers (fig. 1a). The images were processed so that the angles φ_i resulted distinctively. They were used to trace the shape of

the column through a mathematical approach similar to the one applied to the experimental results.

3. Experimental results

The experimental program is based on measurements, which were performed with the consent of patients and their parents.

The patient with a medium “S”-shaped scoliosis was asked to tilt starting from the orthostatic posture, to the right and then to the left in progressive tilting positions with the step of 10 degrees between positions. In each position, a photo has been taken as a reference needed to validate the further mathematically generated shape.

Figure 3 explains the steps of the comparative procedure.

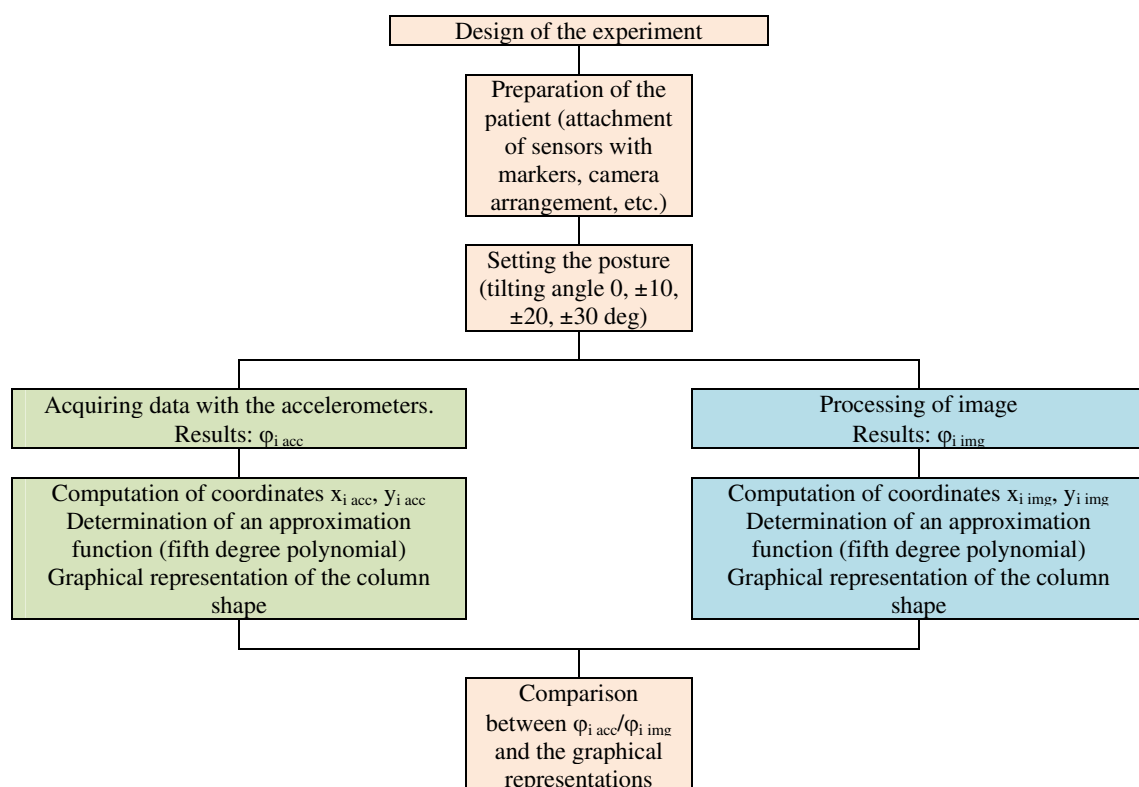


Figure 3. Design of the experiment.

The results of the procedure above are shown in figures 4 ... 8, for the orthostatic posture (0 deg) and four tilted positions (± 10 deg, ± 30 deg). For each position are placed side by side the processed image, the graphical representation of the column got with the sensors (blue) and from the image (red) and the pitch angles resulted from the two approaches.

Comparing the values of the angles and the shapes of the column got through processing data from accelerometers and from direct images respectively, one can make the following notices:

- The reference standard is considered to be the image, which provides sure information regarding the shape of the column.
- The values of the angles are very similar. It is important to observe that the signs of the angles are entirely the same, which is determinant for the shape of the column. Therefore, both methods provide similar concavities, which is relevant for the qualitative and quantitative evaluation of the deformity.

- The difference between the angles is reasonable considering that the measurements are performed onto a biological system, which can not be considered rigid and still. Furthermore, the image sequence is taken at a single moment during a period of several seconds assigned to data acquisition with the accelerometers. The angles from the accelerometers are average values resulted from files recorded in an interval of five seconds, at a frequency of 2Hz.

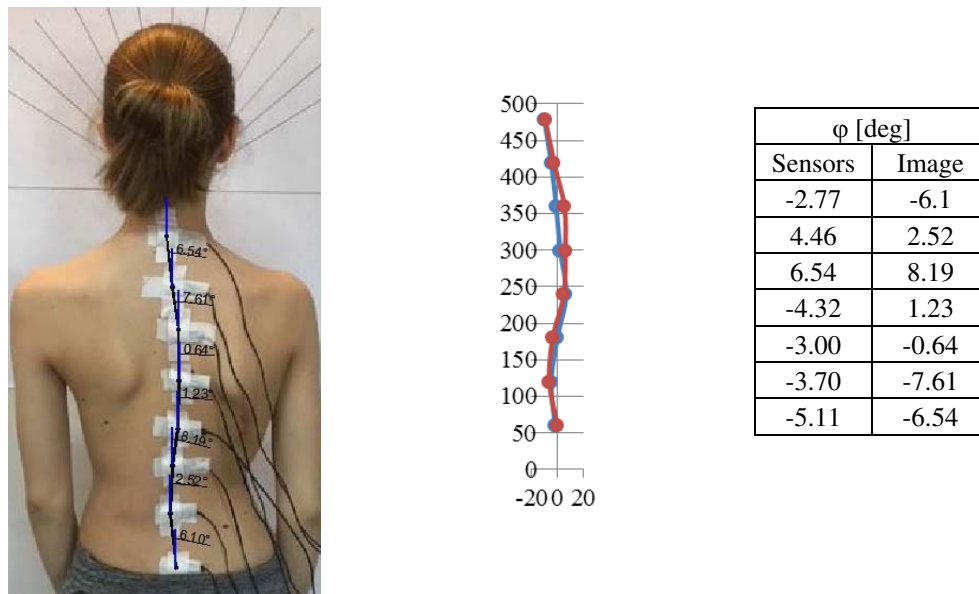


Figure 4. Image, shape of the column and values of pitch angles (0 deg).

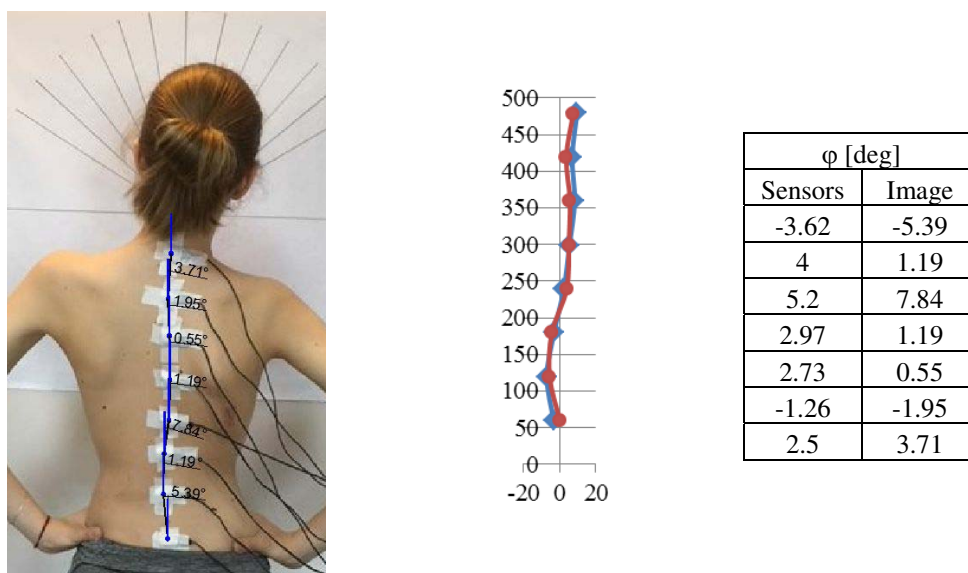


Figure 5. Image, shape of the column and values of pitch angles (+10 deg).

- The shapes of the column, represented on the same graph, are very similar. The differences of the coordinates (x, y) are within the range of units (millimetres), which is considered acceptable.

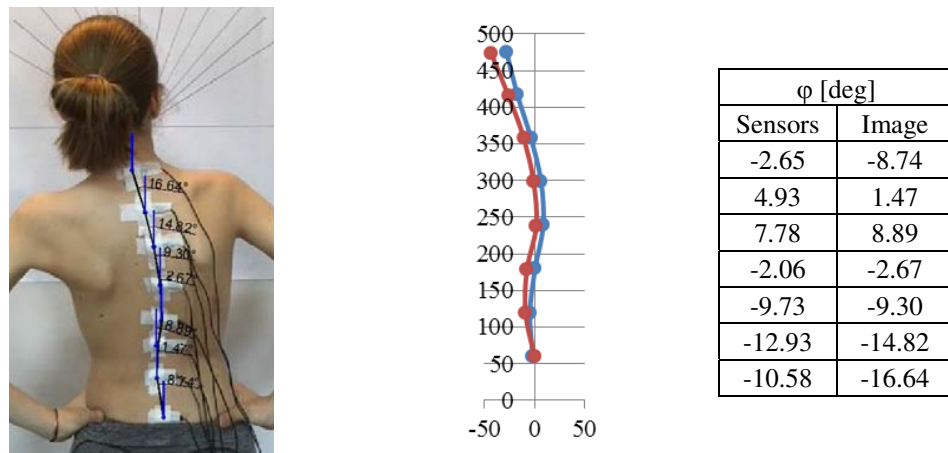


Figure 6. Image, shape of the column and values of pitch angles (-10 deg).

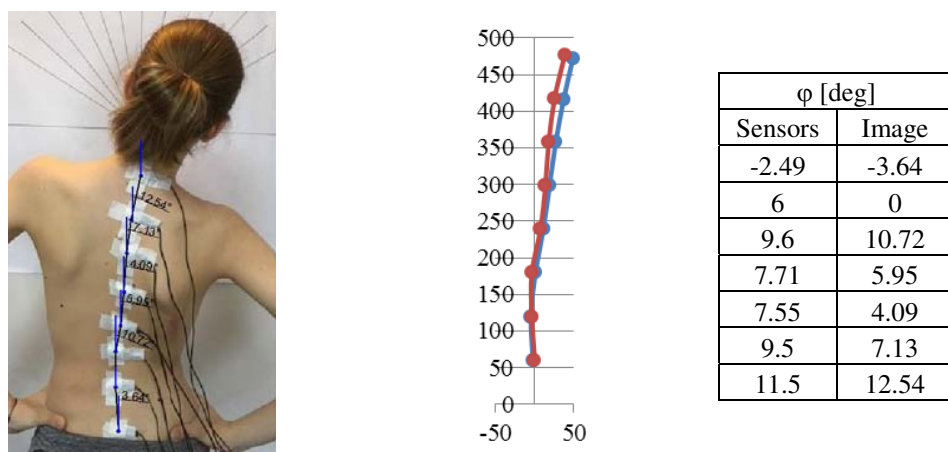


Figure 7. Image, shape of the column and values of pitch angles (+30 deg).

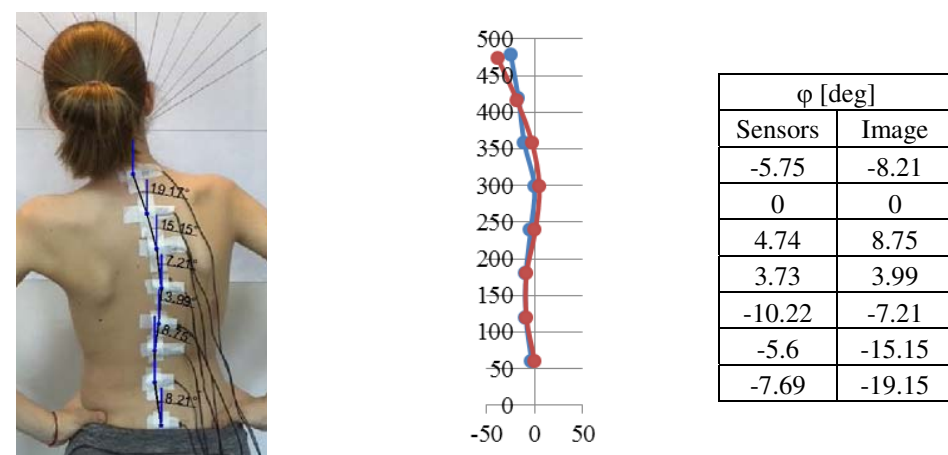


Figure 8. Image, shape of the column and values of pitch angles (-30 deg).

The discussion above allows the conclusion that the method based on acquiring data with the accelerometers is valid. It is considered reliable to be used in further measurements, planned to develop clinical studies regarding vertebral column deformities, such as early diagnosis of scoliosis and subsequent controls but also in assessing the effectiveness of exercises performed in scoliosis rehabilitation programs.

4. Conclusions

Beside the existing methods of investigation of the spinal column, alternative to the traditional X-Ray image, the authors propose a new method based on data acquired from a set of accelerometers, attached on the skin of the patient's back.

As new method, it needs validation by comparison of its results with reference data provided by a sure method. The reference is considered the image taken during acquiring data with the accelerometers.

The results obtained with the new method and the reference data are very similar in regard of pitch angle values and graphical shape. Graphical similarity also validates the mathematical approach, consisting in determination of approximation functions, which were chosen as fifth degree polynomials.

The results of the present work are intended to be used in a study regarding the change of curvatures during exercises conducted by a kinetotherapist within the treatment of scoliosis, with school-age children.

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