Experimental Validation of a New Method for Symmetry Line Detection

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ABSTRACT

In this work a new method for symmetry line recognition, from 3D scanned data of a subject's back, is presented. The new method is validated by comparison with traditional techniques based on cutaneous marking. For this purpose, the upright standing and sitting postures of a sample of 75 subjects, who usually perform different sports activities, are analysed. Error in symmetry line detection is measured as the distance between the estimated symmetry line and the position of the markers. The proposed method is compared with another one described in literature which has been validated in clinical field. Results are analysed and critically discussed.

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1   INTRODUCTION

Every individual assumes a posture when interacting with the surrounding workplace. This adaptability is possible thanks to the complex anatomy of the musculoskeletal system that has a number of degrees of freedom. Thus, a person may assume alternative postures for the same workplace arrangement. However, not all of them are necessarily correct postures. When an incorrect posture is adopted for a long period of time it causes musculoskeletal injury. In fact, extreme or incorrect postures are considered one of the greater risks for musculoskeletal lesions and they are the most prevalent work-related reason for work absence in many industries. Studies, described in published literature, demonstrate that the curvature of the spine is one of the most important characteristics for determining posture, intervertebral disc loads and stresses [12]. Such considerations have led ergonomics researchers to pay particular attention to the posture analysis and prediction for different workers' typologies [13].

Nowadays the traditional techniques for posture and vertebral column detection, based on cutaneous marking [2], [14], [17], can be replaced with modern techniques based on 3D scanner [4], [5], [7], [8], [9], [11]. These techniques offer new detection and diagnostic capacities: 3D scanners are not invasive, give accurate measurements with acceptable costs and prevent posture detection from being conditioned by the instrument. Similarly to the traditional estimative-experimental techniques, the limitations are due to the fact that the evaluations are included in those ones referring to what can be analysed from the outside.

The geometric data relating to a subject's back, as those obtained by means of a 3D geometric scanning (point cloud), cannot be directly used for posture analysis. Data processing becomes, therefore, necessary in order to recognise the characteristic elements of the back, that is to say, those elements identifying the spatial configuration of the vertebral column. This configuration, based on external detection, is given by the position of the vertebral apophyses (symmetry line); from the symmetry line and taking into account the thickness of the soft parts, which cover the vertebra, the spinal midline could be determined [6]. Bergeron et al. [1] and Jaremko et al. [10] developed interesting methods to relate spinal deformities to a set of reliable indexes computed from the external geometry of the trunk.

In this work, a new technique for symmetry line detection, based on an original symmetry index, is presented. The symmetry index identifies the line which divides the back into two mirror-image parts. The proposed technique is validated when inspecting the postures of 75 subjects. The subjects have been analysed in two different postures: standing and sitting. The proposed method for postural analysis is also compared with a method validated in clinical field [7], using, as a reference, the traditional techniques based on cutaneous marking.

2   RELATED WORKS

Symmetry line detection is a very important task which is preliminary to any procedure for spine identification [9], [21]. Symmetry line, defined in the form of a three dimensional curve, furnishes the possibility for a quantitative evaluation of the spine morphology. In order to detect symmetry line, Turner-Smith [20] proposed an approach which consists in measuring the positions of markers appointed in correspondence to the vertebral apophyses. Vertebral apophysis is identified by means of a traditional manual palpation. The symmetry line is detected as the broken line which joins the barycentre of each marker. A similar approach was used by Sodoca et al. [18], which approximated the scanned location of the vertebral apophyses by means of a polynomial curve, making a 3D parametric description of the symmetry line. The main limitation of all these methods is the need to manually identify the apophyses and apply markers.

A different approach consists in acquiring the surface of the subject's back in its full extent, by a 3D scanner, and therefore recognising, from the cloud of measured points, the line which identifies the spinal column. The acquisition of the back surface can provide other useful information regarding posture evaluation such as the trunk torsion at each level of the column. Santiesteban et al. [16] proposed an approach where spine detection is based on the estimation of the principal curvatures' directions and on the joining of "valley points", recognised in horizontal sections, along these directions. Theriault et al. [19] automatically detected the "back valley" on a scoliotic human trunk defined in the form of a tessellated surface. This approach is based on curvature estimation. At each vertex of the mesh and using a quadric fitting method, the points associated to the back valley are identified as those characterized by a strong negative mean curvature. It is important to notice that the spinal column cannot be associated to valley points (or back valley) in any case: usually in the cervical tract the spine is associated to points characterised by a strong positive mean curvature.

In normal subjects, the symmetry line is the line that divides the back into two mirror-image parts. From a geometric point of view, each part can be considered the involutory orthogonal transformation of the other. The symmetry of the spine can be distorted by some ailments such as scoliosis, kyphosis or lordosis, which produce a deviation of the spine from the sagittal plane or torsions. Even in the presence of these anomalies the spine's location can be identified in a local symmetry property. In a healthy subject this symmetry can be recognised in the profile obtained by sectioning the back surface with a horizontal plane.

Symmetry (or asymmetry) can be associated to any point of a plane section of the subject's back, where a function, properly designed to identify symmetry, has the maximum (or minimum) value. Drerup and Hierholzer [7] proposed a methodology (henceforth *DR method*) which is based on the analysis of the symmetry properties of the horizontal sections of the subject's back. A fixed coordinate system is associated to the subject's back, with the vertical axis defined by the prominence of the seventh cervical vertebra and the sacrum. The back surface is sliced by planes perpendicular to the vertical axis. For each slice curve Γ, the point representing the position of the spine is associated to

the minimum value of the *lateral asymmetry function A* defined as follows. Let **p** be a point belonging to a slice curve of the back; the lateral curvature asymmetry A, with respect to $\mathbf{p}(\xi)$, is defined as:

$$A(\mathbf{p}) = \frac{1}{L_0} \int_{u=0}^{L_0/2} a(u) \partial u \qquad (2.1)$$

L_0 is the length of reference, that is, the measure of a neighbour of **p** explored to check symmetry. The partial contributions $a(u)$ are calculated at the points of each slice lying symmetrically to the left (sub-index l) and to the right (sub-index r) of **p**, according to:

$$a(u) = (H_l - H_r)^2 + \frac{\left(G_l^2 - 2G_lG_r\cos(2\varepsilon) + G_r^2\right)}{2}$$

where:

- H = Mean curvature; $H_l = H(\xi - u)$; $H_r = H(\xi + u)$
- G = Gaussian curvature; $G_l = G(\xi - u)$; $G_r = G(\xi + u)$
- ξ is the curvilinear abscissa of the point **p**;
- $\varepsilon = \varphi_l - \varphi_r$ is the difference between the angular orientation of the principal direction in l and r ($k_{1,l}$ and $k_{1,r}$).

The function $A(\mathbf{p}, L_0)$ has value 0 for those points of the curve having a perfectly specular neighbourhood. The value of the length of reference L_0 has an important role, especially if compared with the dimensions of the symmetric portion of the back. Varying the value of L_0 involves different values of *symmetry index*, since it analyses symmetry in a wide and narrow range of the zone investigated. The minimum value of $A(\mathbf{p}, L_0)$ identifies the point that best represents the symmetry of the curve and, therefore, the position of the spine. Since the method is based on surface curvatures calculation (derivatives of second degree), it is particularly sensitive to noises deriving from the acquisition process. These noises cannot be removed with a pre-smoothing of the data without strongly modifying the scanned geometry.

3   THE PROPOSED METHOD

This paper proposes a symmetry index which is based on the analysis of the symmetry in the orientation of the normal vectors of the surface (see Fig. 1). The normal to the vertexes of a tessellated geometric model is less sensitive to noise than those geometric evidences that require the estimation of second-degree differential terms. The proposed method performs the intersection of the surface of the subject's back with a set of horizontal planes. On each of the slice curves Γ_i obtained, the asymmetry function $S(\xi, L_0)$ is evaluated. The asymmetry function verifies the hypothesis that a one-dimensional parametric curve $\Gamma_i(\xi)$ is symmetric at $\mathbf{p}(\xi)$, by comparing the orientations of the normal vectors at opposite points of the curve ($\mathbf{p}(\xi + u)$ and $\mathbf{p}(\xi - u)$), which lie symmetrically with respect to the point $\mathbf{p}(\xi)$. If $\mathbf{p}(\xi)$ is a symmetric point, then, the sum of the normal versors, at $\mathbf{p}(\xi + u)$ and $\mathbf{p}(\xi - u)$, is a versor that has an invariant direction for any value of u:

$$\mathbf{N}(\xi, u) = \frac{\mathbf{n}(\xi + u) + \mathbf{n}(\xi - u)}{|\mathbf{n}(\xi + u) + \mathbf{n}(\xi - u)|}$$

In order to evaluate how invariant the versor $\mathbf{N}(\xi, u)$ is in the investigation zone having length L_0, the standard deviation of $\mathbf{N}(\xi, u)$ is calculated. Normal vectors are described by their components in the slicing plane ($n_x(u)$ and $n_y(u)$) and the vector $\mathbf{N}(\xi, u)$ by its components $N_x(\xi, u)$ and $N_y(\xi, u)$. The mean values of N_x and N_y in the investigation zone are as follows:

$$\overline{N}_x(\xi, L_0) = \frac{1}{L_0} \int_{u=0}^{L_0/2} N_x(\xi, u) du \qquad\qquad \overline{N}_y(\xi, L_0) = \frac{1}{L_0} \int_{u=0}^{L_0/2} N_y(\xi, u) du$$

The standard deviations of each component of the vector $\mathbf{N}(\xi , u)$ are:

$$\sigma_{Nx}(\xi,L_0)=\left(\frac{1}{L_0}\int\limits_{u=0}^{L_0/2}\left(N_x(\xi,u)-\overline{N}_x\right)^2 du\right)^{0.5} \quad \sigma_{Ny}(\xi,L_0)=\left(\frac{1}{L_0}\int\limits_{u=0}^{L_0/2}\left(N_y(\xi,u)-\overline{N}_y\right)^2 du\right)^{0.5}$$

The asymmetry function $S(\xi , L_0)$, at the point $\mathbf{p}(\xi)$, is defined as:

$$S(\xi,L_0)=\sqrt{\sigma_{Nx}^{2}+\sigma_{Ny}^{2}} \tag{3.1}$$

The function $S(\xi ,L_0)$ has value 0 for those points of the curve having a perfectly specular neighbourhood. Since real backs are not perfectly symmetric, the function $S(\xi ,L_0)$ is never 0. Its minimum value identifies the point that best represents the symmetry of $\Gamma_i(\xi)$ and, therefore, the most probable position of the symmetry line. The point where the symmetry function assumes the minimal value is defined as *symmetric point* and it is denoted by $\mathbf{p}_s(\Gamma_i)$.
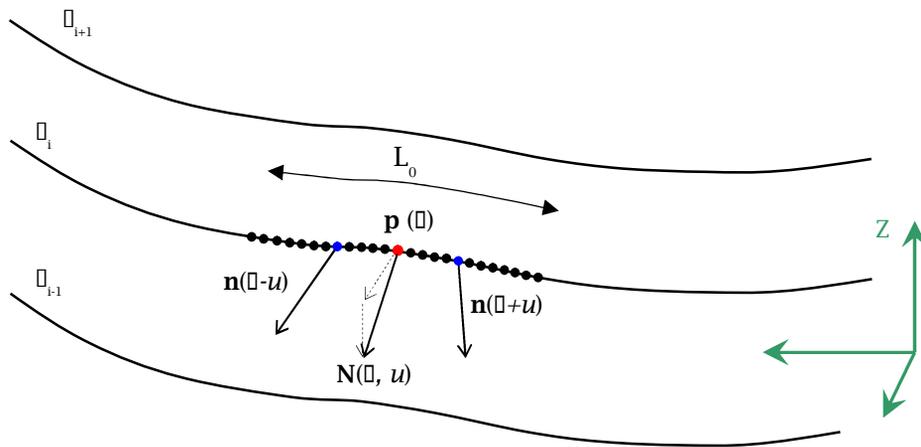
Fig. 1: Definition of the symmetry index S(ξ ,L0).

4 THE PROCEDURE OF COMPARISON

The new method for symmetry line detection (henceforth *AQ method*) has been compared with that one proposed in Drerup and Hierholzer [7] by evaluating 75 real subjects; for each of them two different postures have been analysed: standing and sitting postures.

For this purpose, a specific procedure has been implemented, which consists of the following steps:
- in order to identify a reference evaluation of the symmetry line, markers are positioned in correspondence to the vertebral apophyses, using a traditional approach for posture analysis;
- the back of each subject is acquired in upright standing and sitting postures by a 3D scanner;
- the cloud of measured points is tessellated and transformed into a Eulerian geometric model;
- the tessellated geometric model of the back is sliced by intersecting it with horizontal planes;
- for each slicing curve the symmetric point is evaluated by using the *AQ* and *DR methods*;
- the symmetric points are interpolated by a 3D parametric curve;
- the curves obtained by the two analysed methods are compared with the location of the manually appointed markers.

4.1 Data Acquisition

The geometry of the back has been acquired using a 3D geometric scanner based on structured light. The device used allows us to acquire the whole back of the subject with just one scanning.

For each subject analysed, the symmetry line has been previously identified through a traditional approach, based on tactile detection, which consists in fixing appropriate markers (white adhesive disk with a diameter of *10mm*) in correspondence to the vertebral apophyses. In some cases, due to the presence of thick adipose tissue, the tactile individualization does not yield reliable results. In these cases, the markers have not been fixed. Anyway, the most important anatomic references for the spinal column (Fig. 2) have been detected in each subject analysed. This phase has been repeated before the acquisition of each posture in every subject, so as to avoid those errors caused when the markers no longer identify the apophyses due to the skin gliding movements. For each subject analysed two postures are acquired: standing (Fig. 3) and sitting (Fig. 4) posture.
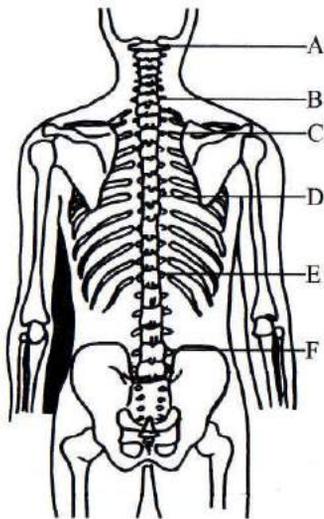
Fig. 2: Anatomic references: A) the first cervical vertebra, B) the seventh cervical vertebra, C) the third thoracic vertebra, D) the seventh thoracic vertebra, E) the twelfth thoracic vertebra, F) the fourth lumbar vertebra.

Fig. 3: Standing posture with the superimposed z axis.
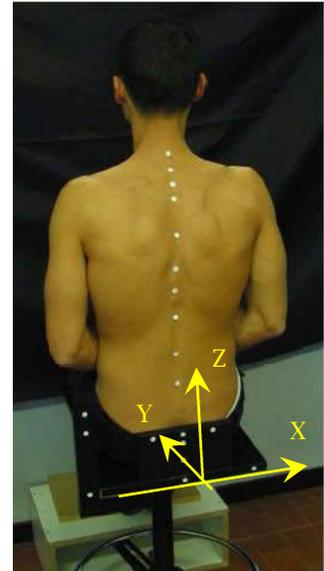
Fig. 4: Sitting posture with the superimposed local coordinate system.

In standing posture the subject puts their arms along their sides, the subject looks straight head in the Frankufurt plane and their legs slightly parted. As a reference for the orientation of the spinal column in a vertical direction, a stadiometer is acquired at the same time as the subject's back.

To acquire the sitting posture, a specifically designed stool has been used. This stool gives us the possibility to acquire, contemporaneously with the subject's back, a reference frame, which is oriented in accordance with the plane of the seat and the subject's legs (Fig. 4). Its main characteristics are:
- it is height adjustable;
- it has a horizontal sitting level to avoid eventual misalignment of the rachis coming from different height positions of the spinal iliac bone;
- a reference local coordinate system is associated to the stool. It is identified by a vertical and a horizontal pole mounted behind the stool. The reference sagittal plane is identified by means of a bar the knees of the analysed subject must touch;

The height of the stool is set to guarantee that the lower limbs (thigh-leg) form an angle of 90° with the sitting level.

For each subject analysed the length of the trunk and other anthropometric parameters are measured. The back is acquired by sitting the person on the stool according to the following constraints:

- the gluteus is in contact with the rear pole;
- the subject looks straight head in the Frankufurt plane;
- the lower limbs form an angle of 90° with the sitting level;
- the knees hold the front bar of the stool;
- the arms are relaxed and hands are placed on top of the knees;

The back is maintained in a natural position, avoiding any forced posture.

4.2   Method's Implementation

Each point cloud acquired is, firstly, transformed in order to align it to the local coordinate system associated to the subject. The acquired points are triangulated to obtain a Eulerian geometric model of the subject's back (a tessellated surface, which consists of a set of adjacent triangles).

The geometric model is sliced by uniformly spaced planes, chosen parallel to the *X-Y* reference plane. The vertexes of the tessellated model which are nearest to the slicing plane are projected onto it (Fig. 5). The implementation of the *AQ* and *DR* methods requires that each slicing curve be analysed. The normal versor and the curvatures are evaluated at slice discretization points. For this purpose, the normal versor and the curvatures at the points $\mathbf{p}(\xi + u)$ and $\mathbf{p}(\xi - u)$, which are at an equal distance from the evaluation point $\mathbf{p}(\xi)$, are estimated by linear interpolation from the values at the nearest points in the slice.
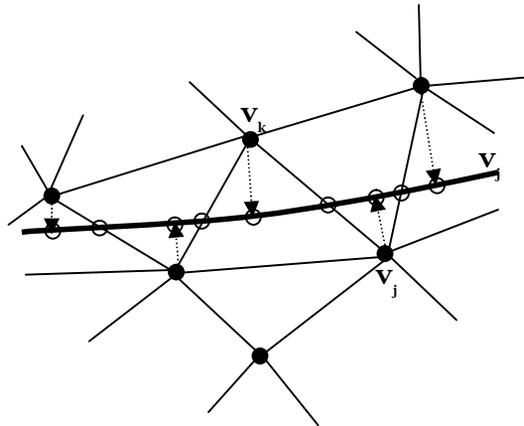
Fig. 5: Building of the slice Γ_i

In order to estimate curvatures and normal versors, the back surface is locally approximated by a biquadric Bèzier surface analyzing, for each point of Γ_i, the 3-ring neighbourhood around $\mathbf{p}$ (Fig. 6). The normal versor $\mathbf{n}(\mathbf{p})$ and the curvatures (Mean and Gaussian) of the path locally approximating the surfaces are assigned to each point $\mathbf{p}(\xi)$ of the slicing curve Γ_i. The approximation with a Bèzier patch provides a local smoothing of the data.

For each Γ_i the asymmetry functions $A(\Gamma, L_0)$ and $S(\xi, L_0)$ are estimated. The most symmetric point is characterized by the minimal values of these functions. In order to analyse symmetry, the asymmetry functions S and A are transformed into the symmetry indexes as follows:

$$w_A = e^{-A(\xi, L_0)}; w_S = e^{-S(\xi, L_0)} \tag{4.1}$$

The domain of the definition of the symmetry index is $w \in \{0,1\}$ and assumes the value 1 for a perfect symmetric point in Γ_i.
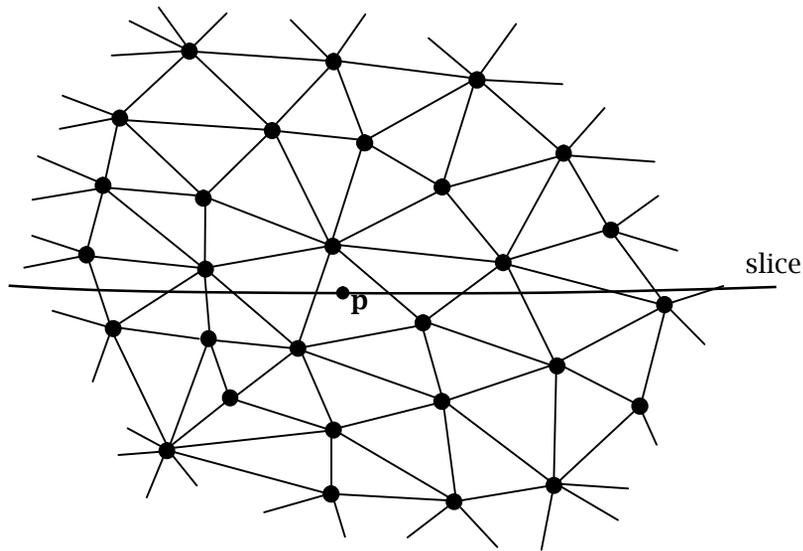
Fig. 6: 3-ring neighbourhood around the **p** point.

5   SYMMETRY LINE RECOGNITION AND APPROXIMATION

The line which is associated to the spinal column is obtained by a weighted approximation of the symmetry points (the weights are the respective w_A and w_S) with a parametric curve $\mathbf{C}(t) = \{x(t), y(t), z(t)\}$. The mathematical functions used in this work have been verified in analogous applications in other works described in literature [1], [5], [16]. It is as follows:

$$x = \sum_{i=0}^{3} a_i t^i \; ; \; y = \sum_{i=0}^{3} \left(b_i \cos kt + c_i \sin kt \right); \; z = t \qquad (5.1)$$

Coefficient a_i, b_i and c_i are calculated by a weighted least square method.

For each slice Γ_i there is a point $\mathbf{q}_{S,i}$ (*AQ* method) or $\mathbf{q}_{A,i}$ (*DR* method) where the symmetry index is maximum. Under the hypothesis that the maximum values of w_A and w_S identify the symmetry line, the curves of the form (5.1) ($\mathbf{C}_A(t)$ and $\mathbf{C}_S(t)$) that best fit the set of points $S_S\{\mathbf{q}_{S,i}\}$ and $S_A\{\mathbf{q}_{A,i}\}$ are two interpretations of the spinal column. Hereafter, these curves will be the *first tentative symmetry lines* and the method will be the *first tentative method*. In Table 1 the curves $\mathbf{C}_A(t)$ and $\mathbf{C}_S(t)$, estimated in 75 real cases (acquired in standing and sitting postures), are compared with the positions of the markers manually appointed on the spinal column (Table 1). The results of this analysis show that the *AQ* method yields better results than the *DR* method in every case.

Posture	Method	overall	lumbar		thoracic		cervical	
			mean	*max*	*mean*	*max*	*mean*	*max*
Standing	*AQ method*	4.2	3.6	9.8	3.9	11.7	5.1	14.9
	DR method	5.1	4.0	12.3	4.6	11.3	5.4	18.7
Sitting	*AQ method*	4.4	3.2	10.9	3.9	16.6	5.6	21.2
	DR method	5.6	4.9	14.6	5.1	15.8	6.3	18.0

Tab. 1: Mean values of the deviation errors (mm) of the curves $\mathbf{C}_A(t)$ and $\mathbf{C}_S(t)$ from the position of vertebral apophyses obtained by the first tentative methods.

In Fig. 7 a sitting posture and a standing posture are compared. In both cases analysed the maps of the normalised symmetry indexes, w_A and w_s, are reported. It is possible to verify that the *AQ* method is less affected by noise than the *DR* Method and, therefore, it is able to discriminate symmetric points with fewer uncertainties. For this reason, the first tentative solution of the symmetry line is more realistic for the *AQ* method than for the *DR* method.

The errors in symmetry line identification strictly depend on the uncertainty in identifying the most realistic symmetric point in each slice of the back. For this purpose, it is important to notice that, depending on the back morphology, in some cases it is not possible to recognise just one point identifying the symmetry line for each slice. In some cases, there could be an entire wide zone in Γ_i where the symmetry index has a quite constant value (Fig. 8) or has more than one maximum (Fig. 9). In these cases, the position of the symmetry line could be associated to relative and not to absolute maximum values of the symmetric index. In order to find an appropriate sequence of symmetry points, all the possible combinations of the sequences of candidate points (in each slice) are approximated by **C**(*t*) and, then, analysed. The number of combinations (*M:* M_{AQ} or M_{DR}) to be analysed is:

$$M = \prod_{i=1}^{n_{slice}} m_{\Gamma,i} \qquad (5.2)$$

Where $m_{\Gamma,i}$ is the number of maxima of the symmetry index in the slice Γ_i.

From all the symmetry line candidates, the most promising curve is that one which minimises the sum of its distances from the approximated points: *estimated symmetry line.* Under the hypothesis that the equation (5.1) is a representative form of the spinal column, this approach for symmetry line detection implicitly selects the set of the most representative points (one for each slice) to be fitted because they are autocorrelated in a 3D form of an actual spine.

In Fig. 10 a typical case of a subject's back is depicted and the points where the symmetry index has its maximum value are marked with a red point. The recognised symmetry line is depicted as a green line. It is possible to verify that, in some slices, the best interpretation for the symmetry line requires a point characterised by a relative maximum of *w* (black point indicated with arrows) and not a point characterised by an absolute maximum (red point): one for the *AQ* method and three for the *DR* method. In all the cases analysed, the criterion used to approximate the symmetry line showed good performances, being the recognised curve the nearest to the real spine configuration.

AQ method	DR method	**Case ID 15:** Female, age *21*, height *162,6 cm*, weight *55 kg. Standing posture*
		Diagnostic classification and identification in conformity with indicative models of sagittal spinal deformity [15]: *Type B* (thoracic hyperkyphosis).
		Clinical observation: kyphosis with reduction of lumbar plexus.
AQ *method*	DR *method*	**Case ID25:** Male, age *21*, height

172 cm, weight 71.4 kg. Sitting posture.

Diagnostic classification and identification in conformity with indicative models of sagittal spinal deformity [15]: *Type A* (physiological aspect of human body trunk).
Clinical observation: moderate kyphosis and normal lordosis.
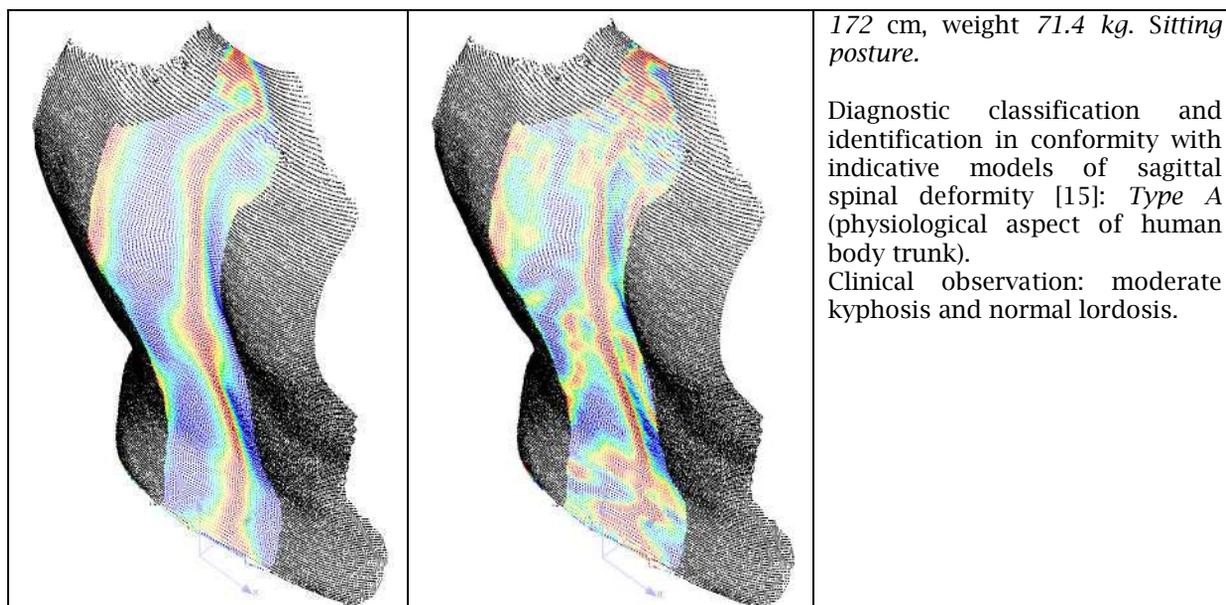
Fig. 7: The map of the normalised symmetry indexes obtained by the presented method (AQ) and by the Drerup method (DR).
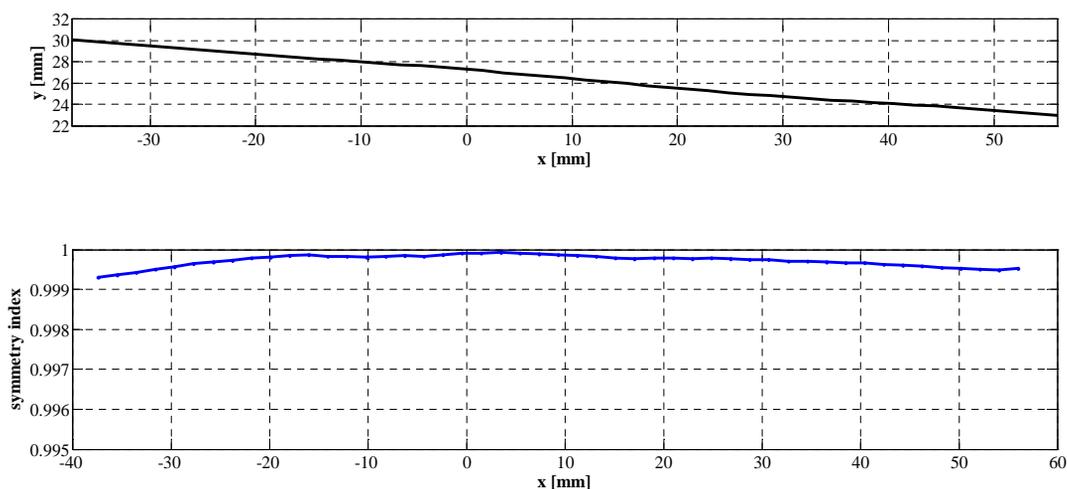
Fig. 8: Slice of the subject's back and its symmetry index characterised by constant value.

6   EXPERIMENTAL RESULTS

The two methods, for symmetry line estimation (*AQ* and *DR*), have been implemented in an original software. The *AQ* and *DR* methods have been compared by analysing standing and sitting postures of a sample of 75 subjects (university students, males and females, aged 20 to 22). In order to characterise the performances of the two methods, the recognised symmetry line has been compared with a traditional way of identification based on manual palpation and cutaneous marking. The recognised vertebral column is analysed by dividing it into three tracts: *lumbar*, *thoracic* and *cervical*. In each of these tracts any deviations of the evaluated symmetry line from the appointed markers are analysed. These deviations are calculated as the minimal distance between the barycentre of the markers and the symmetry line. In Fig. 11, Fig. 12, Fig. 13 and Fig. 14 the histograms of the

relative frequency and the cumulative probability of errors are shown for each method and for each posture analysed.
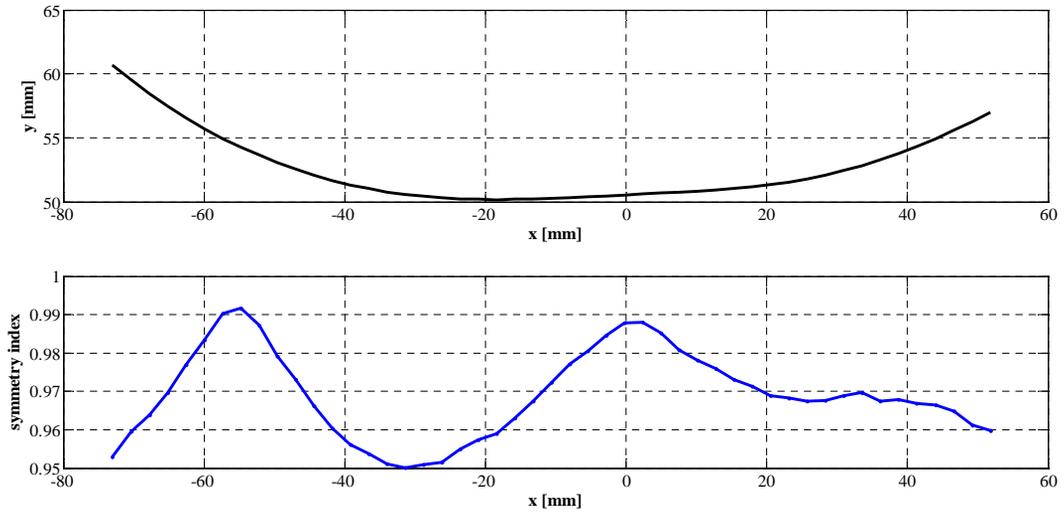
Fig. 9: Slice of the subject's back and its symmetry index characterised by more than one maximum.
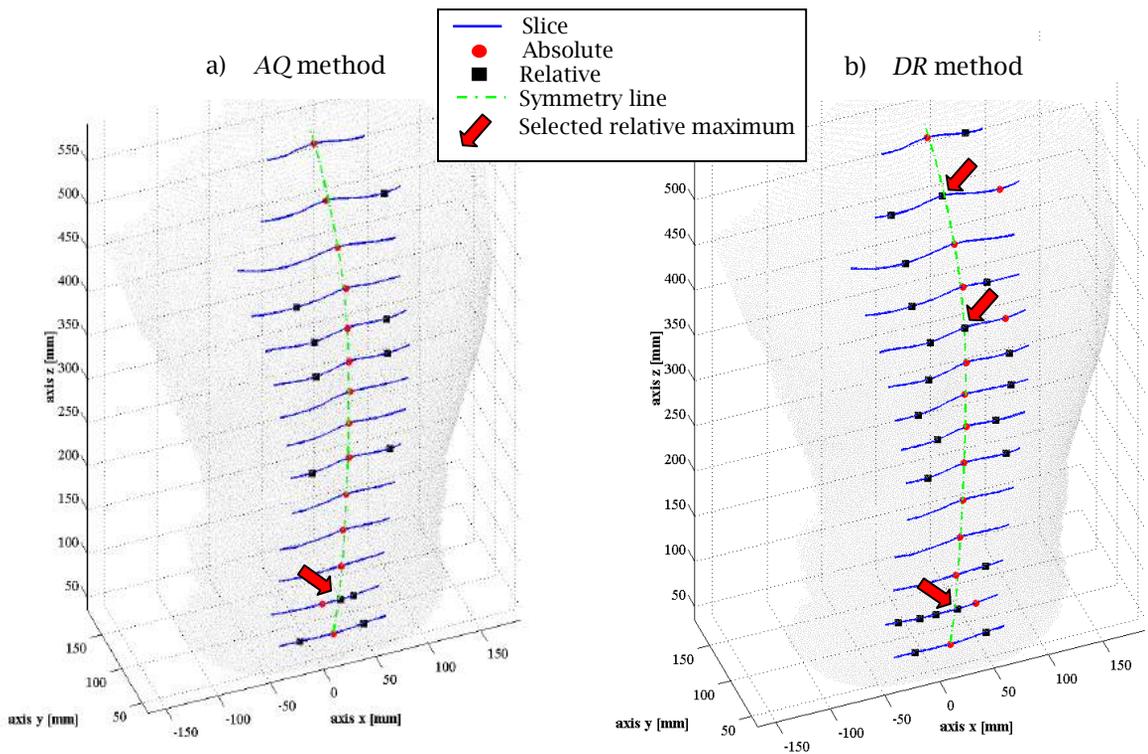
Fig. 10: Maximum of symmetry function w_s (a) and w_A (b) in some slices of the back.
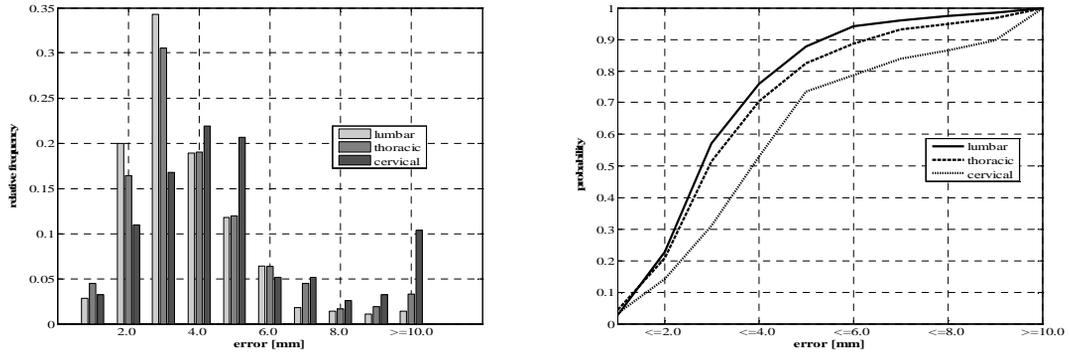
Fig. 11: Relative frequency and cumulative probability of errors for method AQ analysing upright standing posture.
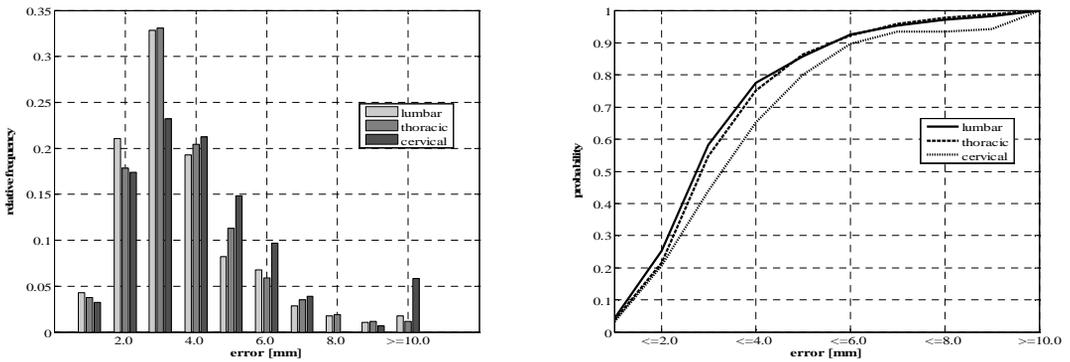
Fig. 12: Relative frequency and cumulative probability of errors for method DR analysing upright standing posture.
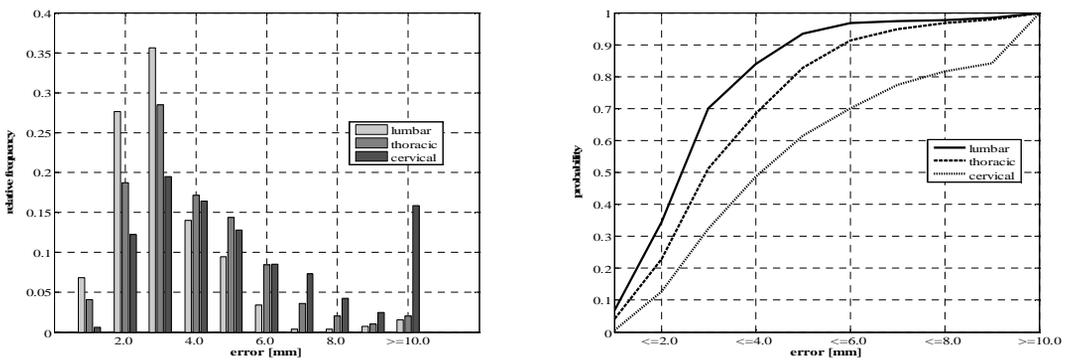
Fig. 13: Relative frequency and cumulative probability of errors for method AQ analysing sitting posture.
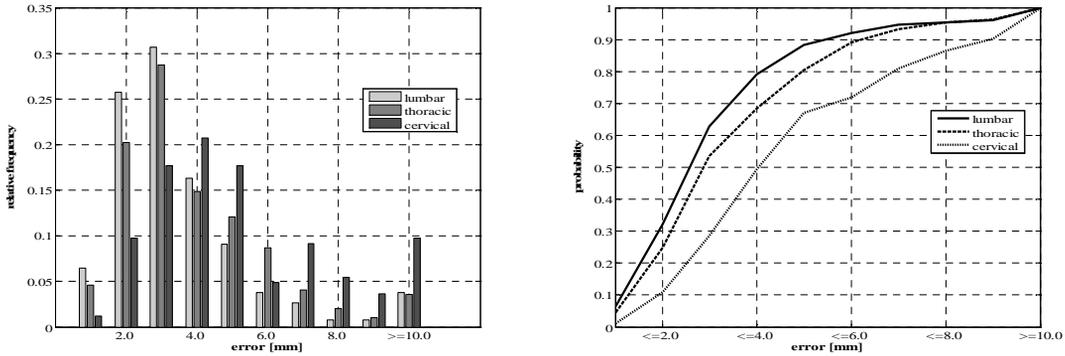
Fig. 14: Relative frequency and cumulative probability of errors for method DR analysing sitting posture.

Both methods yield better results in the lumbar tract. However, some uncertainties are evidenced in the cervical tract. These are due to the natural conformation of the human back, which has a more evident symmetry in the lumbar tract than in the cervical one. In Table 2 the two methods are compared in terms of overall mean and maximum errors produced for each tract of the spine analysed.

Posture	Method	overall	lumbar		thoracic		cervical	
			mean	max	mean	max	mean	max
Upright standing	AQ method	3.84	3.2	7.6	3.5	7.9	4.7	15.6
	DR method	3.67	3.4	12.7	3.4	8.1	3.8	10.7
Sitting	AQ method	3.97	2.8	10.5	3.6	9.2	5.2	15.9
	DR method	4.33	3.7	12.6	3.8	7.4	4.8	22.9

Tab. 2: Mean values of the errors.

The two methods have been also compared by verifying the probability that the error is smaller than an assumed reference value (*5 mm*). This value is the level of accuracy typically achieved in marker positioning [20]. In Table 3 the results are shown.

Posture	Method	lumbar	thoracic	cervical
Upright standing	AQ method	89.64%	87.32%	75.5%
	DR method	85.71%	86.38%	80.0%
Sitting	AQ method	93.5%	82.82%	61.59%
	DR method	88.26%	80.51%	67.01%

Tab. 3: Probability of making errors smaller than 5 mm.

Regarding the upright standing posture, the *AQ* and *DR* methods perform at a similar level of accuracy; the AQ method, in contrast to the *DR* method, produces fewer errors in the lumbar and thoracic tracts, whereas it has greater difficulties in estimating the symmetry line in the cervical tract. The flattened conformation of slices in this tract does not make it possible to correctly discriminate the symmetric points (Fig. 9) with the *AQ* method, which is based on the analysis of the normal to the plane of the slice. In flattened parts of the back the *DR* method detects the symmetric line better because, by using the Mean and Gaussian curvatures, it also takes into account information from outside the slice plane. This little difference in behaviour between the two methods is also evidenced by the analysis of the frequencies of errors (Fig. 11 and 14).

If we analyse the results obtained for the sitting posture, we realise that both methods perform similarly to how they do in the case of the upright standing posture. This implies that, compared with the upright standing position, the considerable pelvic rotation in the sitting posture and the consequent displacement of the vertebrae at the lumbar level, modifies the shape of the back but it is not detrimental to the correct operation of the two methods. As for the cervical tract, the increasingly flatness of this zone accentuates the difference between the errors made by the two methods. In Fig. 15 a slice of the cervical tract and the relative symmetry functions w_A and w_S are quoted. It is possible to observe that the *AQ* method is more selective than the *DR* method, but the latter is able to identify more than one maximum value of the symmetry function. This increases the number of combination of candidate points to be approximated and, therefore, the probability to find a correct symmetry line.

In Fig. 16 the first tentative symmetry lines are compared with the estimated symmetry lines obtained by the two above-mentioned methods.

Although both methods yield similar results, they require very different computational efforts. Due to its low selectivity the *DR* method identified many more candidate points to be approximated than the *AQ* Method, in the analysed cases. In order to recognise the symmetry line in the case shown in Fig. 12, the *AQ* method requires that *972* sequences of candidate points be analysed, whereas the *DR* method needs *262440* sequences. For the cases in Fig. 16, whose maps of the normalised symmetry indexes are depicted in Fig. 7, the M_{DR} are 78732 (ID 15) and *2304* (ID25) respectively, when the M_{AQ} are just *648* (ID 15) and *4* (ID 25). Analogous results have been observed in all the cases analysed.

7   CONCLUSIONS

In this work a new method for *symmetry line* recognition is presented and compared with that one validated in clinical field and proposed by Drerup and Hierholzer [7]. The estimation of the symmetry line obtained by traditional ways of identification of the spine through palpation and cutaneous marking is taken as the benchmark to compare both methods. The comparison between the two methods has been carried out by analysing the upright standing and sitting postures of a sample of 75 subjects. The acquired data have been examined to evaluate the errors in symmetry line detection produced by the two methods. For this purpose, the vertebral column is divided into three tracts: lumbar, thoracic and cervical. In each of these tracts, and for each method, the error in symmetry line detection is measured as the distance between the estimated *symmetry line* and the position of the markers.

The human back cannot be considered a symmetrically perfect geometric surface. For this reason, some uncertainty in spine detection occurs. Owing to the typical conformation of the back, the symmetry functions can have more than one maximum; in these cases, the positions of the spine should be associated to the relative and not to the absolute maximum. The approach adopted to identify the most promising sequence of symmetry points to be approximated, which is based on the minimisation of the sum of the distances between the points to be approximated and the approximating curve, allows us to find the spine quite correctly.

Regarding the cases analysed, the *AQ* and *DR* methods perform at a similar level of accuracy; no significant differences have been found between male and female subjects. The *AQ* method makes fewer errors in the lumbar and thoracic tracts, whereas it has some difficulties in estimating symmetry line in the cervical tract. From a computational point of view, there has been some evidence of great differences between the two methods. This is due to the different number of candidate points that each method identifies in slices. The presented method, just in a first attempt, proves to be capable of finding the most promising set of points to be interpolated; in many cases these points can be adopted without requiring further investigations. On the contrary, many of the points where the value of the symmetry index w_A (*Drerup* method) is maximum do not identify the symmetry line. In all the cases analysed, in order to estimate the symmetry line, the *DR* method required thousands of instances to be investigated to select the most promising set of points, whereas the AQ method required few instances or, at the most, some hundreds of instances.
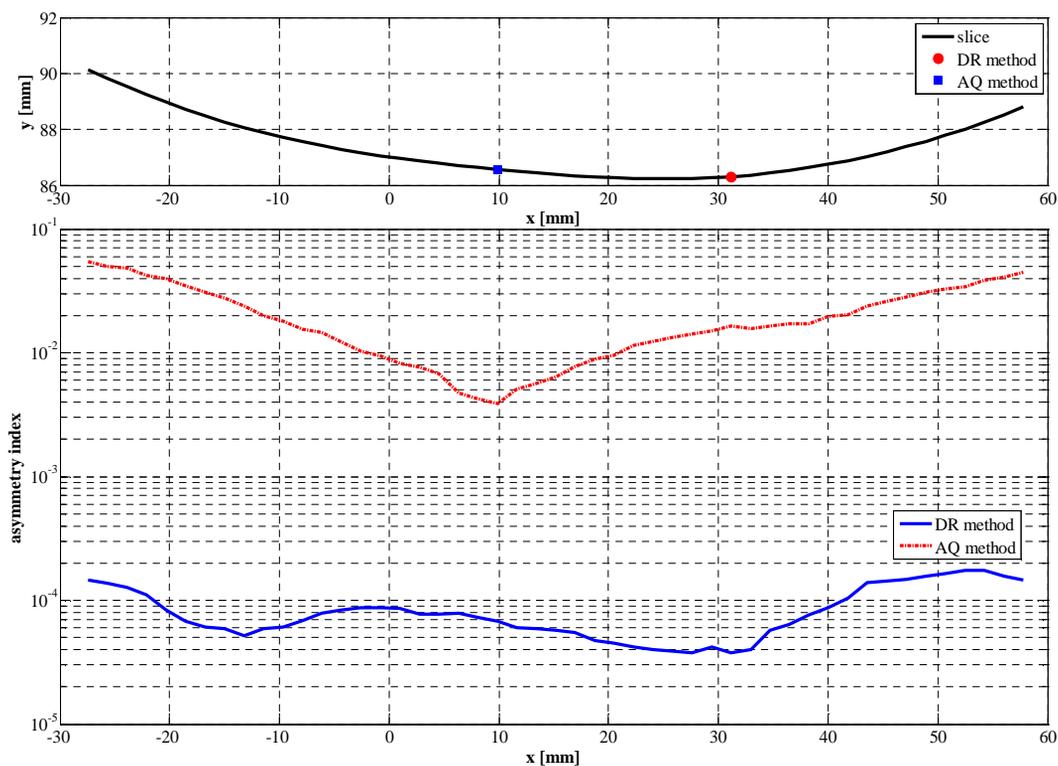
Fig. 15: Comparison of asymmetry functions and symmetric points in a flattened slice in the cervical tract.

A limitation to both methods, which has not been evinced in cutaneous marking, can be due to the body morphology of the subject: a region of hemisome could happen to reveal some gibbosities or alterations having no correlation with the vertebral column deviations which could be merely due to inadequate or incorrect postural attitudes assumed by the subject because of pain or because of daily work and/or sports habits. Another limitation is found in analysing the symmetry indexes by sectioning the back surface with horizontal layers. This approach gives good results in many cases, especially when normal sitting and upright standing postures are analysed, but it could also yield bad results in all those cases where the subject's back is not symmetric with respect to the sagittal plane (it is the case of an unspecific posture with torsion of the trunk). Further work is addressed at extending the symmetry line recognition capability in the case of posture characterised by trunk torsion and lateral flexion.
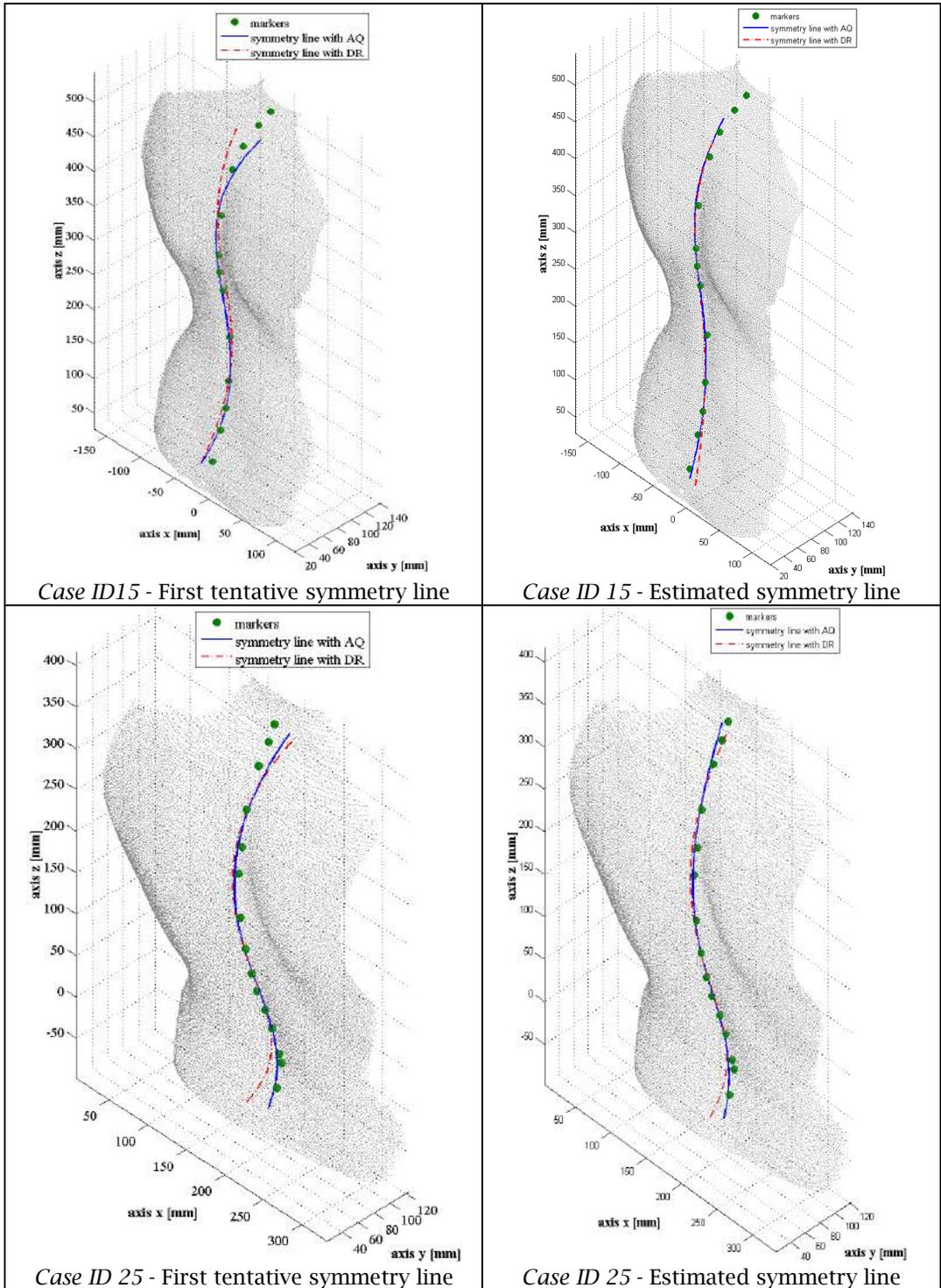
Fig. 16: AQ versus DR method in first tentative and estimated symmetry line.

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