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Human Spine Posture Estimation from 2D Frontal and Lateral Views Using 3D Physically Accurate Spine Model

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SUMMARY This paper proposes the design of a physically accurate spine model and its application to estimate three dimensional spine posture from the frontal and lateral views of a human body taken by two conventional video cameras. The accurate spine model proposed here is composed of rigid body parts approximating vertebral bodies and elastic body parts representing intervertebral disks. In the estimation process, we obtain neck and waist positions by fitting the Connected Vertebra Spheres Model to frontal and lateral silhouette images. Then the virtual forces acting on the top and the bottom vertebrae of the accurate spine model are computed based on the obtained neck and waist positions. The accurate model is deformed by the virtual forces, the gravitational force, and the forces of repulsion. The model thus deformed is regarded as the current posture. According to the preliminary experiments based on one real MR image data set of only one subject person, we confirmed that our proposed deformation method estimates the positions of the vertebrae within positional shifts of 3.2 ∼ 6.8 mm. 3D posture of the spine could be estimated reasonably by applying the estimation method to actual human images taken by video cameras.

key words: *spine, posture estimation, dynamic simulation, X-ray CT images, MR images*

1. Introduction

Since bad posture is one of the causes for lower back pain, spine posture is very important for keeping a comfortable life in our daily life. For example, If we keep a bad posture for long time, or lift up a heavy object quickly, the spine will be damaged due to stress working on a spine, and then our health breaks down.

The method for analyzing the stress working on a vertebra has been studied [1]. However, the stress is computed under the assumption that the force working on the vertebra is the force caused when a subject is straightening his back. Because we cannot measure the position and direction of the vertebra easily when the subject is taking the posture such as flexion or lateral bending, we cannot estimate the force acting on the vertebra.

In this paper, we describe the models and methods for estimating the position and direction of a vertebra accurately from human images taken by conventional video cameras. By using our proposed methods, it will be possible to calculate the stress working on the spine of the subject taking any posture.

Many human models are proposed for estimating the human posture. In these models, each part of the human body is approximated by a cylinder, an ellipsoid [2], and surfaces [3]. Postures are generated by controlling the positions of cylinders or ellipsoids and the joint angles. Rehg et al. proposed a kinematic model and templates for solving occlusion problems [4]. Plänkers et al. [5] introduced a metaball-based human model for estimating the human posture or motion from actual human images. However, the estimated results are not very accurate, since physical dynamics properties of each part of a human body and interactions among the others are not considered, and the posture is estimated by fitting the model to the human image based on least squares method or Inverse Kinematics.

On the other hand, models and methods for generating human posture and motion are also proposed [6], [7]. The models used in these methods consist of rigid segments and joints with one, two, or three degrees of freedom. The rigid segment has the physical properties such as mass and moment of inertia for dynamic simulation. Postures are generated by Inverse Dynamics in addition to Forward and Inverse Kinematics. Then the resulting posture is reproducing actual human posture well. However, it is impossible to estimate a human posture by using these models, because these models are not designed to be applied to the posture estimation.

This paper describes a physically accurate spine model and its application to estimate three dimensional spine posture from the frontal and lateral views of a human body taken by two conventional video cameras. In the estimation process, we obtain the neck and waist positions by employing a simple silhouette-based matching method from the successive two sets of human images. Then the forces acting on the models are calculated from the obtained displacements of the neck and waist positions and the time interval. Then the deformation of the spine model is determined based

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on the dynamic simulation. The deformed model is regarded as the current posture. In Sect. 2, we describe two kinds of models approximating human spine. Section 3 shows the spine posture estimation process. In Sect. 4, we show the evaluation results about the accuracy of the model deformation process using real MR images. The experimental results of application of the estimation method to real human images are also shown in this section.

2. Models

We use two kinds of models, Connected Vertebra Spheres Model and the accurate spine model. These two models approximate human spine at different levels of detail, and have the different control parameters for deformation.

2.1 Connected Vertebra Spheres Model

Connected Vertebra Spheres Model consists of connected spheres and control points as shown in Fig. 1 [8]. The connected spheres are a series of spheres (vertebra spheres) that approximate the vertebrae of the spine. Each sphere is always connected to the adjacent spheres each other when the model is deformed to generate postures such as the flexion or the lateral bending postures. The vertebra sphere holds a set of control points representing the outer shape of a human body. These control points are placed on a control plane associated with each vertebra sphere. The 3D shape of the human body is obtained from a set of rectangle polygons based on the control points on adjacent control planes. In the model deformation process, as a vertebra sphere rotates, the associated control plane rotates, and the control points on its plane rotate accordingly.

We construct a generic model by using a set of X-ray CT images provided by the Visible Human Project [9]. A model for individual subject is generated by deforming the generic model in the estimation process. The generic model is constructed by the following processes. Bone regions are extracted from the input CT images by thresholding. Then the frontal and lateral views are obtained by projecting the extracted regions. The center and the radius of each vertebra sphere are determined from these views manually. The control points of each sphere are located on the contour of the subject every 30 degrees by hands.

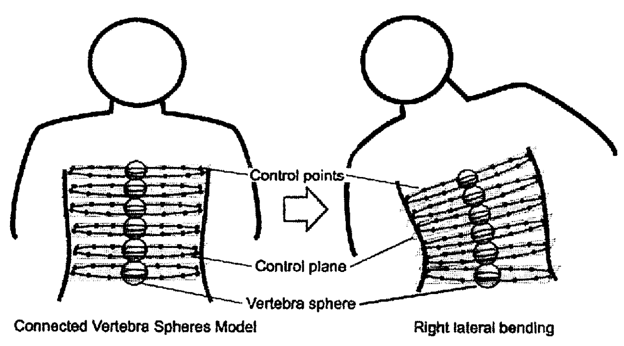


Fig. 1 Connected Vertebra Sphere Model. Spine is modeled as the vertebra spheres and control points. The vertebra spheres approximate the vertebrae of the spine. The vertebra sphere holds a set of control points for representing the outer shape of a human body. The control points are placed on a control plane associated with each vertebra sphere.

2.2 Accurate Spine Model

We model a vertebra as a rigid body composed of a set of particles as shown in Fig. 2. The positions of particles belonging to a vertebra are indicated by the positions of voxels in the corresponding bone region in a set of CT images. We can obtain the positions of the particles by thresholding the CT images simply.

Each vertebra holds the physical parameters such as a relative mass property, a center of mass, and components of an inertia tensor characterizing the physical properties of the vertebra. These parameters can be calculated from the number and the positions of the particles belonging to the vertebra. When we denote mass and 3D coordinate of the i-th particle associated with the vertebra as m_i and (x_i, y_i, z_i), respectively, the relative mass property and the center of mass of the vertebra are calculated by the following equations, respectively,

$$M = \sum m_i, \tag{1}$$

and

$$\boldsymbol{x}_g = \left(\sum m_i x_i, \sum m_i y_i, \sum m_i z_i\right)^{\mathrm{T}} / M, \tag{2}$$

where $\boldsymbol{x}_g$ is the column vector. Then the inertia tensor is expressed by the following equation,

$$I = \begin{pmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{pmatrix}, \tag{3}$$

where the elements of the tensor are derived as shown

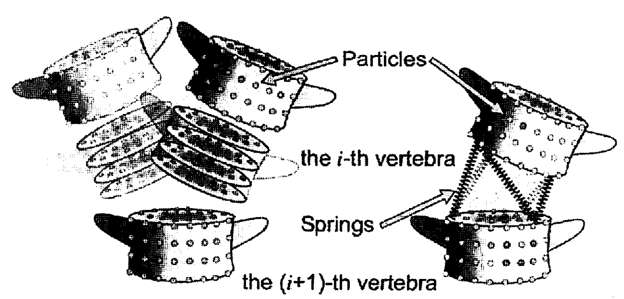


Fig. 2 Accurate spine model. Each vertebra is modeled as a rigid body composed of a set of particles. The upper and lower vertebrae are connected by a set of springs.

in the following equations,

$$I_{xx} = \sum m_i(\bar{y}_i^2 + \bar{z}_i^2), \tag{4}$$

$$I_{yy} = \sum m_i(\bar{z}_i^2 + \bar{x}_i^2), \tag{5}$$

$$I_{zz} = \sum m_i(\bar{x}_i^2 + \bar{y}_i^2), \tag{6}$$

$$I_{xy} = I_{yx} = \sum m_i \bar{x}_i \bar{y}_i, \tag{7}$$

$$I_{xz} = I_{zx} = \sum m_i \bar{x}_i \bar{z}_i, \tag{8}$$

$$I_{yz} = I_{zy} = \sum m_i \bar{y}_i \bar{z}_i. \tag{9}$$

In these equations, $\bar{x}_i$, $\bar{y}_i$, and $\bar{z}_i$ indicate the coordinate of the i-th particle relative to the center of mass, $\boldsymbol{x}_g$ calculated by Eq. (2).

An intervertebral disk is modeled as an elastic body composed of springs connecting the upper and the lower vertebrae. The movement of two vertebrae in the deformation process are constrained by the springs.

3. Spine Posture Estimation

3.1 Neck and Waist Positions Estimation

Figure 3 shows the processing flow of the spine posture estimation method using Connected Vertebra Spheres Model and the accurate human spine model. The inputs are a sequence of the frontal and lateral views of a subject. Two cameras taking the input images are placed at the places where their optical axes satisfy orthogonal.

We generate silhouette images corresponding to two input images at frame t by thresholding. At this time, the position and orientation of Connected Vertebra Spheres Model are arranged where the model's waist corresponds to the waist on the silhouette images. Then posture candidates are generated by applying the model deformation method based on two primitive operations to the model. The outer shape of the obtained candidate is constructed by the rectangle polygons with adjacent four control points. Then the outer shape is

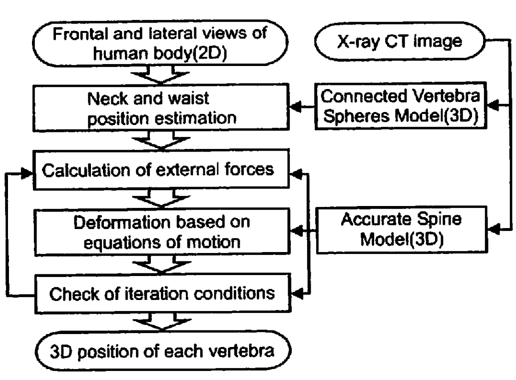


Fig. 3 Processing flow of the spine posture estimation using Connected Vertebra Spheres Model and the accurate spine model.

projected onto the silhouette images. The number of pixels in the exclusive regions between the projected regions and the silhouette regions are calculated to measure a matching rate of the actual and the generated postures, and the most fitting candidate is estimated as the current posture. We simply regard the top and bottom vertebrae of the estimated spine as the neck and waist positions.

3.2 Deformation of Accurate Spine Model

The accurate spine model is deformed so as to locate the top and bottom vertebrae of the model on the neck and waist positions, respectively. This process is carried out by solving a set of equations of motion. The external force $\mathbf{F}_{\text{ext}}$ acting on the vertebrae is expressed as the sum of the gravitational force $\boldsymbol{f}_g$ and the intervertebral disk force $\boldsymbol{f}_{\text{disk}}$.

The intervertebral disk force $\boldsymbol{f}_{\text{disk}}$ occurs when the disk is compressed by the upper and lower vertebrae. In our model, we assume that the force of repulsion that is caused by a spring is defined as the following equation,

$$T_i = \frac{-\boldsymbol{l}_{ij}}{|\boldsymbol{l}_{ij}|}\left[k_{ij}(|\boldsymbol{l}_{ij}| - |\boldsymbol{l}_{ij}^0|) + c_{ij}\frac{\boldsymbol{v}_{ij}\cdot\boldsymbol{l}_{ij}}{\boldsymbol{l}_{ij}\cdot\boldsymbol{l}_{ij}}\right], \tag{10}$$

where $\boldsymbol{l}_{ij}$ and $\boldsymbol{l}_{ij}^0$ are the lengths of the spring linking the i-th point of contact on the surface of a vertebra at current frame and the j-th point of contact on the surface of an adjacent vertebra at initial frame of the posture estimation, respectively. $\boldsymbol{v}_{ij}$ is the derivative of $\boldsymbol{l}_{ij}$ with respect to t. The second term on the right side of Eq. (10) is the attenuation factor in terms of velocity. c_{ij} and k_{ij} are a spring constant and a damping coefficient, respectively. $\boldsymbol{f}_{\text{disk}}$ acting on a vertebra is expressed by the sum of the force of repulsion caused by the springs attached to the vertebra.

In order to deform the accurate spine model so as to locate the top and the bottom vertebrae on the neck and the waist position, respectively, we introduce two virtual forces $\boldsymbol{f}_{\text{neck}}$ and $\boldsymbol{f}_{\text{waist}}$ acting on two vertebrae as shown in Fig. 4. Let $\boldsymbol{x}'_{\text{top}}$ and $\boldsymbol{x}'_{\text{bottom}}$ be the positions of two vertebrae estimated by the deformation process of the accurate spine model at the previous frame, and $\boldsymbol{p}_{\text{neck}}$ and $\boldsymbol{p}_{\text{waist}}$ the positions of the neck and the waist obtained by the rough estimation at the current frame. Then these forces are expressed as

$$\boldsymbol{f}_{\text{neck}} = \mathrm{M}_{\text{neck}}(\boldsymbol{p}_{\text{neck}} - \boldsymbol{x}'_{\text{top}})/\Delta t^2, \tag{11}$$

$$\boldsymbol{f}_{\text{waist}} = \mathrm{M}_{\text{waist}}(\boldsymbol{p}_{\text{waist}} - \boldsymbol{x}'_{\text{bottom}})/\Delta t^2, \tag{12}$$

where M_{neck} and $\mathrm{M}_{\text{waist}}$ are the masses of two vertebrae. Δt indicates the time interval between the two successive input images.

The process of the model deformation is divided into two steps. In the first step, the set of equations of motion are solved under the condition that the two

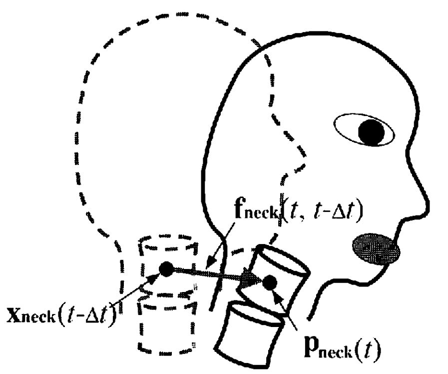


Fig. 4 The force $\boldsymbol{f}_{\mathrm{neck}}(t,\ t-\Delta t)$ acting on the top vertebra of the accurate spine model. $\boldsymbol{x}_{\mathrm{neck}}(t-\Delta t)$ is the neck position obtained by the accurate estimation process at time $t-\Delta t$. $\boldsymbol{p}_{\mathrm{neck}}(t)$ is the neck position obtained by the rough estimation process at time t.

virtual forces work on the top and bottom vertebrae in addition that the forces, $\boldsymbol{f}_{\mathrm{g}}$ and $\boldsymbol{f}_{\mathrm{disk}}$ work on whole the vertebra. The external force $\mathbf{F}^i_{\mathrm{ext}}$ acting on the i-th vertebra is expressed by the following equations,

$$\mathbf{F}^i_{\mathrm{ext}} = \begin{cases} \boldsymbol{f}^i_{\mathrm{g}} + \boldsymbol{f}^i_{\mathrm{disk}} + \boldsymbol{f}_{\mathrm{top}} & \text{for top vertebra,} \\ \boldsymbol{f}^i_{\mathrm{g}} + \boldsymbol{f}^i_{\mathrm{disk}} + \boldsymbol{f}_{\mathrm{bottom}} & \text{for bottom vertebra,} \\ \boldsymbol{f}^i_{\mathrm{g}} + \boldsymbol{f}^i_{\mathrm{disk}} & \text{otherwise.} \end{cases} \tag{13}$$

The velocity and the angular velocity with respect to each vertebra are computed and then the position of each vertebra is calculated.

Because an intervertebral disk is modeled as a set of springs, the vertebrae are oscillated after performing the first step of the deformation. Therefore, the model is deformed again by solving the set of equations of motion under the condition that the movement of the top and bottom vertebrae are fixed as expressed in the following boundary conditions,

$$\boldsymbol{x}_{\mathrm{top}} = \mathbf{0}, \tag{14}$$

$$\boldsymbol{v}_{\mathrm{top}} = \mathbf{0}, \tag{15}$$

$$\boldsymbol{x}_{\mathrm{bottom}} = \mathbf{0}, \tag{16}$$

$$\boldsymbol{v}_{\mathrm{bottom}} = \mathbf{0}. \tag{17}$$

The external force $\mathbf{F}^i_{\mathrm{ext}}$ acting on the i-th vertebra is calculated simply as the following equation instead of Eq. (13),

$$\mathbf{F}^i_{\mathrm{ext}} = \boldsymbol{f}^i_{\mathrm{g}} + \boldsymbol{f}^i_{\mathrm{disk}}. \tag{18}$$

The deformation process described above is carried out iteratively until the both following conditions are satisfied,

$$|\boldsymbol{p}_{\mathrm{neck}} - \boldsymbol{x}_{\mathrm{top}}| < t_{\mathrm{neck}}, \tag{19}$$

$$|\boldsymbol{p}_{\mathrm{waist}} - \boldsymbol{x}_{\mathrm{bottom}}| < t_{\mathrm{waist}}, \tag{20}$$

where t_{neck} and t_{waist} are predetermined thresholds. The outputs are 3D position and the orientation of each vertebra.

4. Experimental Results and Discussion

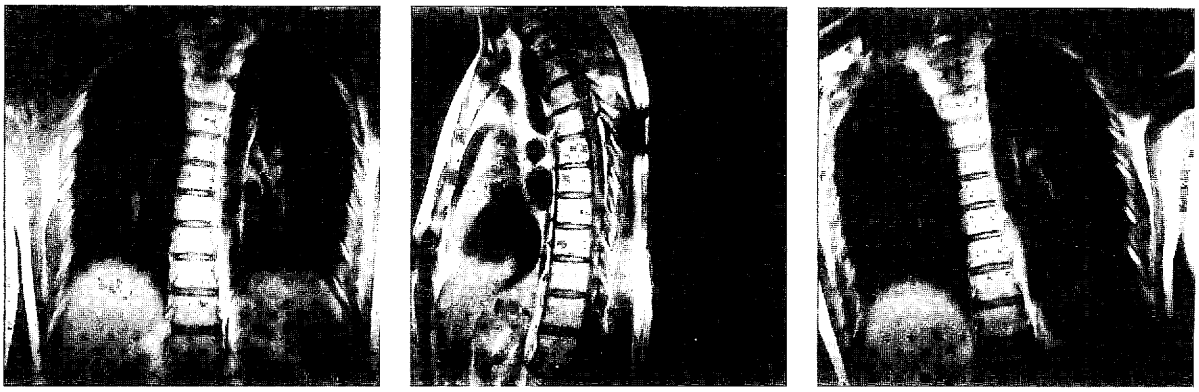
4.1 Evaluation about the Accuracy of the Model Deformation Method Using MR Images

We evaluated the accuracy of the method for deforming the accurate spine model described in Sect. 3.2. In this experiment, we used three sets of MR images, named A, B, and C as shown in Fig. 5. The first two sets A and B were the coronal and sagittal images in which a subject was lying straightly on the bed of MRI. The other set C was the coronal images in which the subject was lying with his body bending to the right. Acquisition parameters of the MR images were: 512 × 512 pixels, 0.586 mm pixel size, 7 slices. The reconstruction pitch was 15 mm for the image sets A and C, 8 mm for the image set B.

From the sets A and B, we measured a center of mass, vertical height, sagittal diameter, transverse diameter of a vertebra, and distance between vertebrae, and we constructed an accurate spine model reflecting the structure of the spine of the subject based on these parameters. We also measured the vertebra positions of the subject bending his body to the right from the set C. The neck and waist positions were determined by the obtained vertebra positions. Then the accurate spine model was deformed, and we compared the estimated results of the vertebrae with the vertebra positions measured from the set C. Because we took only the coronal images about the bending posture, we could not obtain the coordinate of a vertebra in the direction of the sagittal axis. Therefore, we assumed that the coordinate of a vertebra in the direction of the sagittal axis does not change during the deformation process, and the movements of the vertebrae were limited on the plane parallel to the coronal plane.

In this experiment, the number of iteration for converging oscillation of the springs in the deformation process was adjusted to 80 times. The parameters $\boldsymbol{f}_{\mathrm{neck}}$ and $\boldsymbol{f}_{\mathrm{waist}}$ were calculated from Eqs. (11) and (12) under the assumption of $\Delta t = 0.8$ secs. The spring constant k_{ij} and the damping coefficients c_{ij} were manually adjusted so that the shape of the deformed model should become close to the shape of the spine of the subject taking right lateral bending posture. There are rotational angles around the center of mass about a vertebra as parameters that determine the posture of the vertebra. However, these parameters could not be obtained from MR images. Therefore, we adopted the parameters obtained from the X-ray CT images used in the model construction.

Table 1 shows the evaluation results for deforming the accurate spine model. In this table, Δx and Δy mean the errors along the left-right direction and along the longitudinal direction, respectively. SSD means the sum of squared differences. The unit of the values is



(a) (b) (c)

Fig. 5 Representative images of each of the three MR image data sets for evaluation on the accuracy of the model deformation method. (a) and (b) are one of the coronal and sagittal images (data sets A and B). In these data sets, a subject was lying straightly on the bed of MRI. (c) An example of coronal images (data set C). In this data set, the subject was lying with his body bending to the right.

Table 1 The evaluation results of the method for deforming the accurate spine model. The values in this table indicate the distance between the estimated vertebra positions and the vertebra positions measured from real MR images. Δx and Δy mean the errors along the left-right direction and along the longitudinal direction, respectively. SSD means the sum of squared differences. The unit of the values is millimeter. The abbreviation 'T' and 'L' represent thoracic and lumbar vertebra, respectively.

Vertebra	Δx	Δy	SSD
T1	1.9	0.2	1.9
T2	2.3	3.7	4.4
T3	3.2	−0.4	3.2
T4	6.8	0.1	6.8
T5	6.6	0.7	6.6
T6	5.3	1.4	5.5
T7	4.1	0.7	4.1
T8	3.7	2.0	4.2
T9	2.8	2.5	3.8
T10	1.8	2.8	3.3
T11	2.6	3.9	4.7
T12	2.3	2.7	3.6
L1	3.9	4.9	6.3
L2	3.3	4.5	5.6
L3	2.5	5.2	5.7
L4	2.2	5.7	6.1
L5	0.0	0.2	0.2

millimeter. The abbreviation 'T' and 'L' represent thoracic and lumbar vertebra, respectively.

We implemented our proposed method on a conventional PC (Pentium 4 2.8 GHz). Total computation time was 88.15 seconds. 98% of the processing time was spent for the iteration process for attenuation of the springs. The model deformation process was repeated 16 times until the top vertebra reached to the neck position obtained from the MR images.

4.2 Application to Real Human Images Taken by Video Cameras

First, in order to evaluate the accuracy of the neck and waist position estimation process described in Sect. 3.1, we manually specified the neck and waist positions on the frontal and lateral views of human images. The estimated positions are compared with the manually specified positions. The images of 19 subjects were used in this experiment. Each of the subjects took lateral bending posture. The experimental results showed that the average error of the estimated waist positions was about 3.3 cm.

Then we applied the proposed method to the real human images for evaluating efficiency of spine posture estimation. The inputs are frontal and lateral views taken by conventional video cameras. The size of images is 320 × 240 pixels. The subject was sitting on a chair, and he was straightening his back in the first frame of input sequences. Then, he bent his body slowly.

Figures 6 and 7 show the estimated results of the spine postures. The estimated spine postures are overlaid on figures. We have tested our method on a conventional PC (Pentium 4 1.5 GHz). Total computation time for one posture was 159.3 seconds, and it took 7.10 seconds per one iteration of the procedure of the accurate spine model fitting.

4.3 Discussion

As shown in Table 1, our deformation method estimated the vertebra positions within positional shifts of 3.2 ∼ 6.8 mm. From MR images shown in Figs. 5 (a) and (c), we found that the center of mass of the vertebra 'T4' shifted in 6.2 cm from its original posture. The proposed method estimated the 'T4' shifted in 6.8 mm (Table 1). When we consider the shift measured on MR images as a gold standard, the error of the estimated position is about 11%. For the 'T9', its error also becomes 11%.

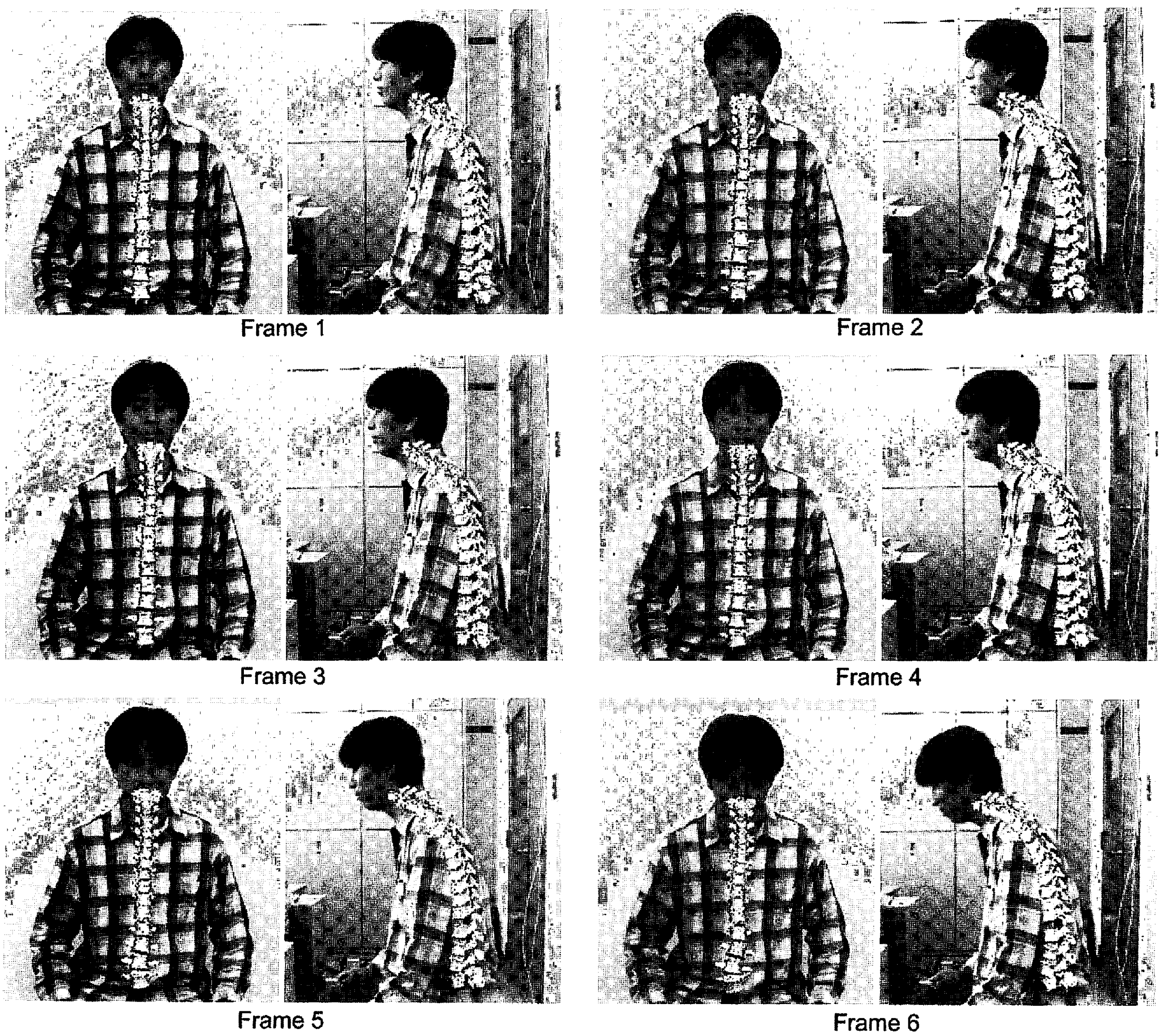


Fig. 6 Estimation results of the flexion posture using accurate spine model.

Since the final objective of our study is to estimate physical load on vertebrae from human images, the errors about the estimated vertebra positions need to be discussed from the point of view of the accuracy of the forces applied to the vertebrae. In the following discussion, in order to calculate the forces acting on a vertebra, we use the Schultz's model [10] that considers the equilibrium of forces. When the forces applied to one vertebra equilibrate (Fig. 8), we have the following equations,

$$C - E = W_t + W_h + W_l + W_r, \tag{21}$$

$$l_E \times E = l_t \times W_t + l_h \times W_h + l_l \times W_l + l_r \times W_r. \tag{22}$$

By eliminating the parameter E from Eqs. (21) and (22),

$$C = \frac{1}{l_E}(l_t \times W_t + l_h \times W_h + l_l \times W_l + l_r \times W_r) + W_t + W_h + W_l + W_r. \tag{23}$$

In Eq. (23), we use the following parameters, W_h = 35 N, W_l = 32 N, W_r = 32 N, W_t = 252 N, and l_E = 13.5 cm, adopted in the reference [10]. We assume that the distances between the vertebra and the two arms are l_r = 20 cm and l_l = −20 cm. By measuring l_t and l_h from the MR images used in this experiment, l_t, l_h are set to 3.4 cm and 14.7 cm, respectively. We can calculate the force C = 458 N from Eq. (23) by using these parameters. Then if the vertebra shifts in 6 mm, the applied force becomes C = 471 N. Therefore, if a vertebra position can be estimated with the error of 6 mm, it would be possible to estimate the force applied to the vertebra with the error of 2.8%.

In the deformation process, case of bending of a

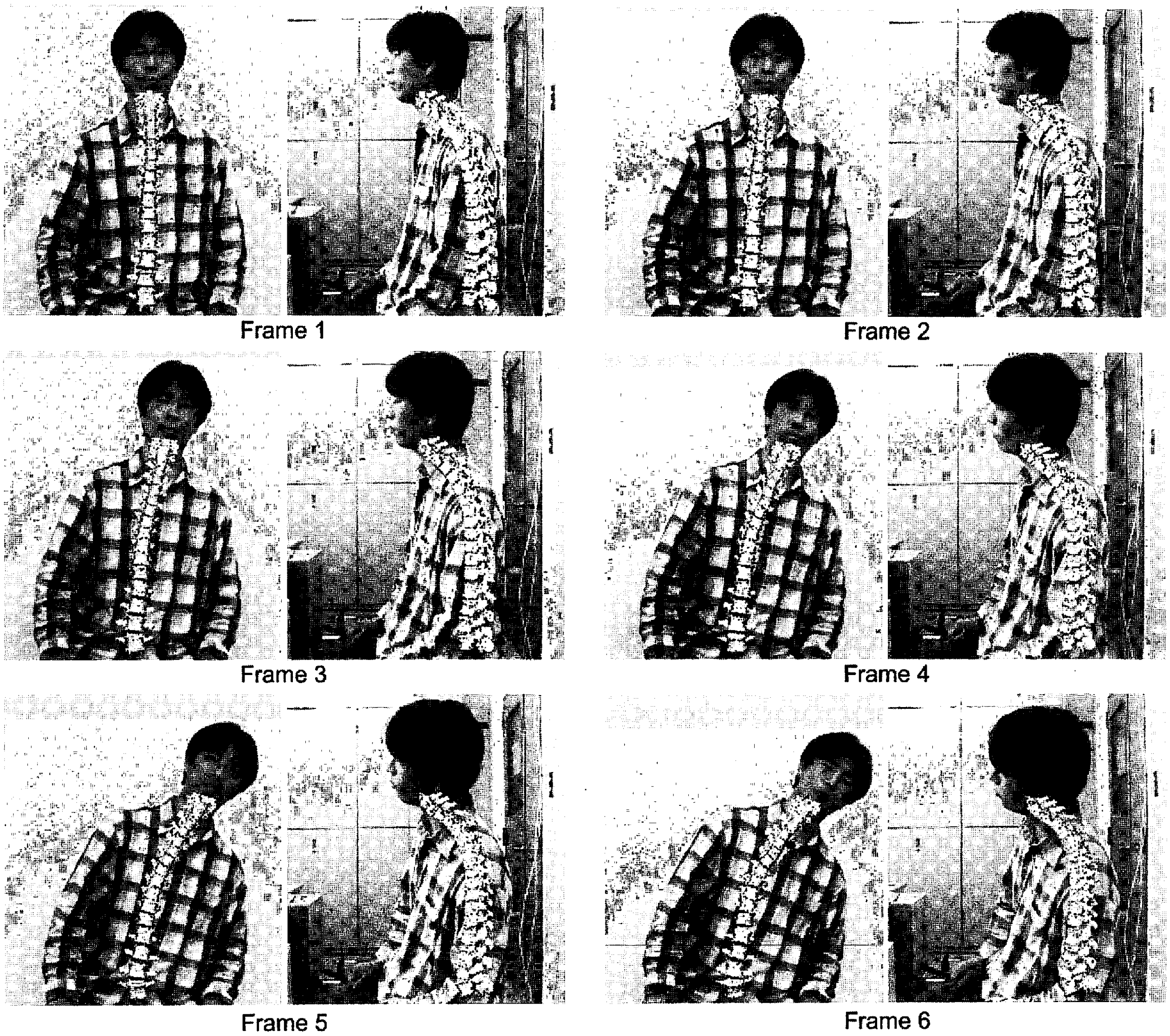


Fig. 7 Estimation results of the lateral bending posture using accurate spine model.

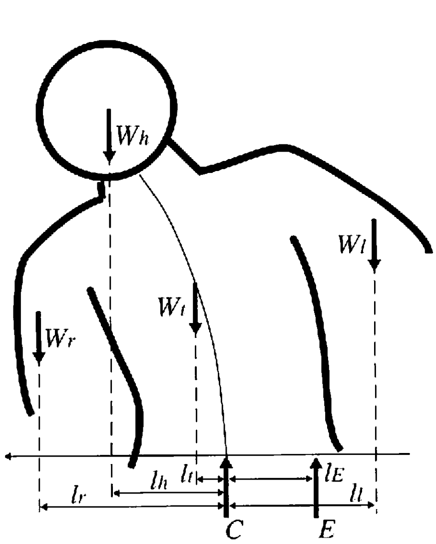


Fig. 8 Equilibrium of the force applied to a vertebra.

vertebra depends on the direction of the vertebra, the spring constants, and the damping coefficients of the springs that link the vertebra and the adjacent vertebra. We could not determine the parameters about the rotation angles around a center of mass about a vertebra in the experiments. As a result, the directions of two vertebrae adjacent to each other changed rapidly. The force of repulsion expressed by Eq. (10) depends on the position and the direction of a vertebra relative to the adjacent vertebra. A vertebra moves so as to conserve the relative position and direction in the process of the iterative computation for the convergence of oscillation of springs. Therefore, the directions of vertebrae may affect the estimation results. In future, we should measure the directions of vertebrae from MR images, and perform the re-experiment for evaluation.

In the experiments, spring constants and damping coefficients were adjusted manually. Then if these parameters can be optimized, it will be possible to estimate the vertebra positions more accurately. One way to determine the parameters is to estimate them from MR images. For the estimation, we will adopt the sum of the distances between the estimated results and the vertebra positions measured from MR images as a cost function, and find the parameters for which this function becomes smallest. We can evaluate the accuracy of the deformation method by estimating the vertebra positions using thus obtained parameters, and by comparing them with the vertebra positions measured from other MR images.

The human spine posture is estimated reasonably as shown in Figs. 6 and 7. It could be possible to estimate flexion and lateral bending posture. In the case of the twisting posture estimation, the body direction, which can be obtained by the positions of both shoulders, would be needed as additional constraint. Our approach is effective for fitting the model with articulated structure to an actual human image. It may be applicable to estimate arm and leg posture or motion.

On the Frames 4, 5, and 6 in Figs. 6 and 7, the directions of some vertebrae change fairly relative to the directions of the adjacent vertebrae, or the distances between the two adjacent vertebrae are considerably large. This is mainly because the springs, which are approximating the intervertebral discs, were not attached to the vertebrae with respect to the center of mass symmetrically. Hence, the forces created by the upper and lower intervertebral discs do not equilibrate. For more precise estimation of a spine posture, we need to improve the method calculating the external forces acting on the vertebrae.

5. Conclusion

In this paper, we have proposed an accurate human spine model and a method for estimating the spine posture from frontal and lateral views of human body taken by two video cameras. Each vertebra is approximated as a rigid body composed of a set of particles. An intervertebral disk is modeled as springs connecting the upper and the lower vertebra in our model. Rough positions of the neck and the waist are estimated using simple model from the images. Two virtual forces acting the top and the bottom vertebrae are computed based on the obtained positions. The accurate posture of the spine is estimated by deforming the model under these forces. The model is deformed by solving the equations of motion. From the experimental results of comparing the vertebra positions measured on MR images with the estimated vertebra, we confirmed that our deformation method can estimate the vertebra positions within positional shifts of 6.8 mm. Our method estimated 3D posture of the human spine reasonably from the experimental results of application to actual human images.

Future work includes: (1) application to a large set of human images to validate efficiency of the method, (2) development of a method that generates a personal model from the generic spine model constructed from a set of X-ray CT images, and (3) development of a method for calculating the loads acting on the spine.

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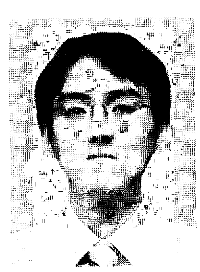

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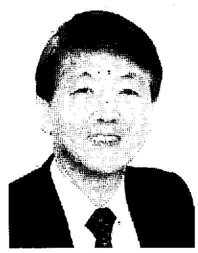

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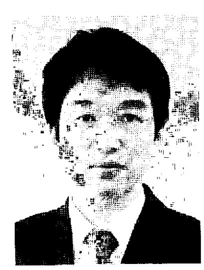

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