



# **Automatic recognition of vertebral landmarks using videofluoroscopic images: an alternative for spine kinematics**

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## **Abstract**

Recognition of landmarks represents a difficult problem in the field of spine kinematics. Automatic software for the selection of the position of vertebrae in a sequence of videofluoroscopic images has been developed as a means removing the need for manual making of bony landmarks. Lumbar coronal and sagittal images are sequentially grabbed from a videofluoroscopic device. Videofluoroscopy produces dynamic x-ray images using low radiation exposure but results in relatively poor images. Due to this poor quality and the absence of reference points, a method of statistical recognition based upon recursive cross-correlation has been developed to track the motion of vertebrae. A template was built using a specific region around each vertebra analysed. The cross-correlation between the template and the subsequent images estimates the displacement and the rotation of each vertebra. The results are statistically corrected to improve accuracy and to maintain the aspect ratio. Therefore a more precise landmark detection is performed.

The assessment of the method was performed using videofluoroscopic images of a calibration model comprising two lumbar vertebrae linked using an universal joint. Error analysis suggests that this method improves the accuracy of the kinematics calculations required to diagnose back pain.

## **1 INTRODUCTION**

The measurement of motion in the human spine is of interest because of the relationship between spinal mechanics, mechanical damage, back pain and disability.



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The inaccessibility of the spine makes it necessary to use X-ray machines and image processing techniques. Videofluoroscopy, in particular, permits accurate kinematics analysis using a low X-ray dosage to provide an image sequence. The main problem in using this technique is the poor quality of the images obtained, which do not contain easily recognisable landmarks. As the images are not very clear the selection and tracking of points on the vertebrae for different stages of the movement becomes very difficult. Large errors in the identification of the kinematics parameters may result from relatively small errors in the measurements of the input co-ordinates[5]. Manual intervention, in particular, is regarded as the major contributor to the errors[6]. In order to minimise the manual interaction, a program which allows an automatic and precise identification of vertebrae landmarks, has been developed. This, after the vertebra landmarks have been selected in the first frame of sequence, gives the co-ordinates of the corresponding landmarks found in subsequent images. Applying statistical recognition and a rigid model fitting technique an accurate measurement is obtained.

## 2 METHODS

Due to the poor quality of videofluoroscopic images (low Signal to Noise Ratio, poor definition and contrast), previous efforts to precisely identify the vertebrae positions, through landmark recognition using different image processing techniques, have been ineffective. To overcome these problems a new statistical approach has been developed.

The recognition process is based on a recursive cross-correlation algorithm between templates in two subsequent images. Assuming that  $T$  and  $M$  are two matrices representing the Template and a part of the subsequent image respectively, equation 1 gives the expression of the cross-correlation function.

$$\frac{\sum_{i,j} T(i,j) \cdot M(i,j)}{\sqrt{\sum_{i,j} T^2(i,j) \cdot \sum_{i,j} M^2(i,j)}}$$

Equation 1

Being the cross-correlation an index of similarity, it has a maximum value which can be used to identify the same structure in different locations.

The algorithm exists as a sequence of different stages. The first stage concerns the estimation of the position of the vertebrae centres in the next image using the vertebrae template through cross-correlation (fig. 1). Then, rotating the template, the angles of rotation are grossly computed. To enhance the precision a further cross-correlation is evaluated using the four corner templates and the regions of the next image near to their estimated position. To further enhance

the precision of the co-ordinates identified a statistical correction is performed to ensure the assumption of vertebral rigidity[7]. Finally, the intervertebral angles and the instantaneous centres of rotation are computed.

According to previous works[4], since the spinal processes are often very difficult to recognise, the "corners" of the vertebra body are selected as efficient landmarks for its localisation. The template to perform the first cross-correlation is chosen so to include the entire body of the vertebra (fig. 1), taking care not to enclose parts of other vertebrae. Consequently, the template and vertebrae centres almost coincide. Since the template is a part of the initial image, it contains the maximum available information. The same procedure is applied for

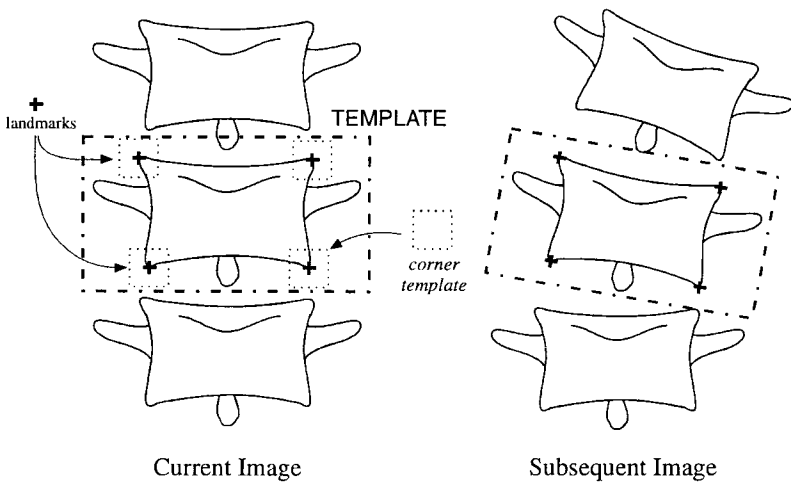


Figure 1: Use of templates for the recognition procedure

the four corner templates (fig. 1). All subsequent templates can be derived from the four landmarks. The images, with a size of 512 by 512 pixels (256 grey levels) were grabbed from a videotape using image processing software (Optimas). The computational implementation of the cross correlation technique was carried out partly with the Matlab Image Processing toolbox and partly under a C environment. A fluoroscopic image sequence of the bending of a calibration model, consisting of L3 and L4 lumbar vertebrae, was used for validation purposes. L3 was progressively rotated with 5 degree increments about L4 which was held fixed. The parameters extracted for the clinical investigation were the relative rotations between the vertebrae and this instantaneous centre of rotation (ICR).

The entire procedure is being applied to image sequences of both healthy and pathological subjects. The lumbar spine, in particular, is being investigated during bending about the coronal (fig. 2) and sagittal planes.



### 3 RESULTS

The results showed a identification of the vertebral landmarks. The validation procedure demonstrated errors of the order of  $10^{-1}$  degrees and  $10^{-3}$  meters in the degree of vertebral rotation and in the ICRs location respectively.

The algorithm is also robust with respect to the contrast level of the images.

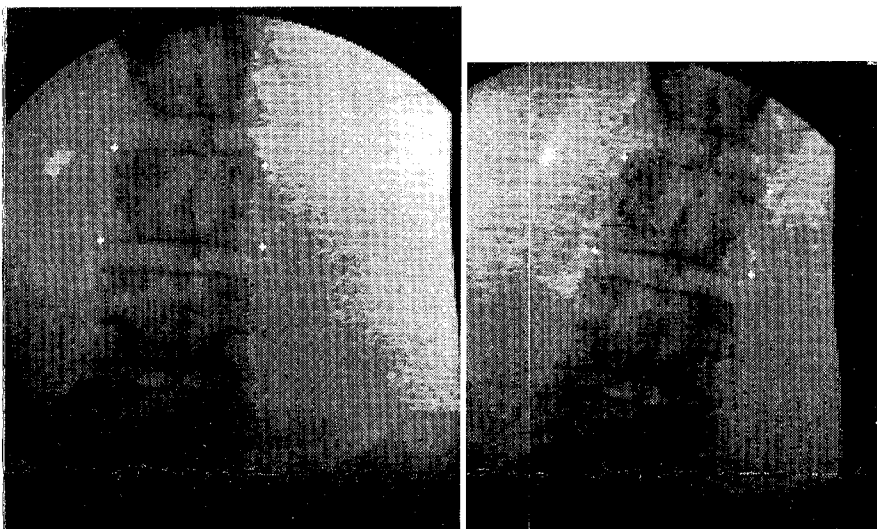


Figure 2: Vertebral landmarks identified automatically two subsequent images.

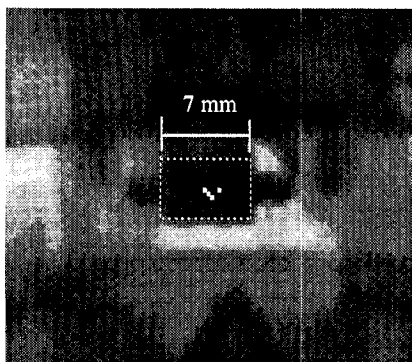


Figure 3. Computed ICRs for the calibration model

Fig. 3 shows an enlargement of the universal joint connecting the vertebrae of the calibration model with the resulted ICRs marked in white. The true centre is, naturally, in the middle of the joint.



## 4 CONCLUSION

The method developed allows easy and fast processing of the large amount of image data required for spinal motion analysis. Error analysis suggests that this method gives a considerable improvement in the accuracy of the kinematics calculations.

A priori knowledge could be included to attempt three-dimensional analysis which may overcome problems which arise from the coupled motion of the spine whereby axial rotation accompanies lateral bending. The use of tracking algorithms and an extensive error analysis could further improve the feature extraction capability.

The technique presented is a general purpose method that could be applied to the recognition of moving joints, for example, in the assessment of prosthetic implant motion and in monitoring progress in rehabilitation therapy.

## REFERENCES

### 1. Books:

1. Gonzalez R. C., Woods R. E., *Digital Image Processing*, AddisonWesley publishing company 1992
2. Jain A. K., *Fundamentals of Digital Image Processing*, Prentice Hall International, 1989
3. Mood A. M., Graybill F. A., Boes D. C., Introduction to the theory of statistics, McGraw-Hill Book Company, 1974

### 2. Paper in a journal:

4. Breen, A. C., Brydges, R. , Nunn H. ,Kause J. and Allen R.; Quantitative Analysis of Lumbar Spine Intersegmental Motion. *European Journal of Physical Medicine and Rehabilitation*. Vol. 3 n. 5 December 1993
5. Panjabi, M. Centers and Angles of Rotation of Body Joints: A Study of Errors and Optimization. *Journal of Biomechanics*, 1979, 12, 911-920
6. Panjabi, M., Chang, D., Dvorak, J., An Analysis of Errors in Kinematics Parameters Associated with in vivo Functional Radiographs. *Spine*, 1992, 2 - 200-205

### 3. Paper in conference proceedings:

7. Simonis C., Allen R., Breen A., Rigid Model Fitting Technique: an Alternative in the Selection of Landmarks on Spinal Images. pp 103-104 *Proceedings of the V Symposium on Biomedical Engineering*, Santiago de Compostela, Spain 1994