Lumbar Spine Location in Fluoroscopic Images by Evidence Gathering

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Abstract. Low back pain (LBP) is a very common problem and lumbar segmental instability is one of the causes. It is important to investigate lumbar spine movement in order to understand instability better and as an aid to diagnosis. Digital videofluoroscopy provides a method of quantifying the motion of individual vertebrae, but due to the relatively poor image quality, it is difficult and time consuming to locate landmarks manually, from which the kinematics can be calculated. Some semi-automatic approaches have already been developed but these are still time consuming and require some manual interaction.

In this paper we apply the Hough transform (HT) to locate the lumbar spinal segments automatically. The HT is a powerful tool in computer vision and it has good performance in noise and partial occlusion. A recent arbitrary shape representation avoids problems inherent with tabular representations in the generalised HT (GHT) by describing shapes using a continuous formulation. The target shape is described by a set of Fourier descriptors, which vote in an accumulator space from which the object parameters of translation (including the *x* and *y* direction), rotation and scale can be determined. At present, this algorithm has been applied to the images of lumbar spine, and has been shown to provide satisfactory results. Further work will concentrate on reducing the computational time for real-time application, and on approaches to refine information at the apices, given initialisation by the new HT method.

1 Introduction

Low back pain remains a very common complaint that affects an estimated 80 percent of adults during some period in their life. Low back pain has been, and continues to be, one of the enigmas of modern medicine. Low back pain and its associated disability have appeared to escalate despite the considerable technical advances in diagnosis, treatment and rehabilitation. The direct and indirect cost of low back pain is enormous. For example, it has been estimated that chronic low back pain annually results in 225,000 to 300,000 lumbar surgeries and an estimated direct and indirect medical cost of $75 to $100 billion in the US [1].

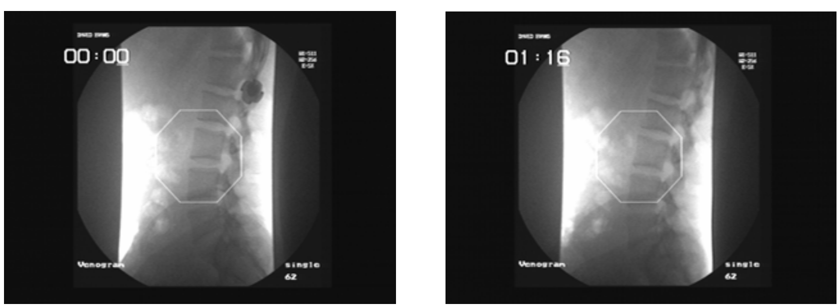

Figure 1: (A) The first frame of a lumbar Spine sequence. (B) The second frame of the sequence.

Back pain has been studied widely. An important mechanical cause is spinal instability. Weiler [2] suggested that 20 percent of low back pain patients have spinal instability. Many experts such as Gertzbein [3], Ogston [4], Panjabi [5] and Kanayama [6] have devoted considerable effort to this subject. Gertzbein [3] applied a Moiré Fringe method to measure the motion of lumbar vertebrae L4-L5 moving from full extension to full flexion. Ogston [4] described an *in vivo* method to study the centrode pattern at the L4-L5 and L5-S1 (where L denotes lumber vertebra and S denotes the Sacrum) levels. Panjabi [5] suggested that the neutral zone is more closely associated with clinical instability than is the range of motion by applying external fixators to the cervical spine. Kanayama [6] used a template method to obtain the kinematic parameters for studying of the differences among lumbar segments.

Despite the wide acceptance of instability, it is still the subject of much discussion and controversy. It is often held that instability may cause abnormal movement, so study of spinal movement could be helpful in its

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definition and may benefit diagnosis and clinical surgery. At present X-rays provide the only practical method of obtaining images for analysis of motion study. However, traditional X-ray techniques suffer from the high radiation dosage involved in obtaining a series of views of motion, so only a few static images are usually obtained. It is very difficult to study spinal motion with such limited data. Videofluoroscopic imaging was then developed to study lumbar spinal instability. This technique can be used to obtain a series of dynamic frames of spinal motion with lower X-ray dosage than that required for a single plain X-ray plate.

For studying of spinal kinematics, locating landmarks on a moving vertebra is required before motion analysis. This task was originally done entirely manually. Due to poor image quality, it is difficult to place markers exactly on the vertebral corner and furthermore, repeatability cannot be assured. In order to overcome these difficulties, automatic algorithms have been developed. Simonis [7] [8] used a template matching method, in which a template comprising the whole vertebral body was defined. Muggleton and Allen [9] obtained some improvement by using an annular template, which was defined by outer and inner templates. In this method, only the part between these two templates was correlated with the whole image to find the shape. This can speed the process but it was still based on template matching, on a single image, which may suffer when out-of-plane motion is evident.

2 Current Work

In this paper we show how a new version of the GHT can be used to locate vertebra shape. The theory of the HT is quite simple. In line extraction, points in the image are transformed into lines in a slope-intercept space. Lines in the slope-intercept space (also called the accumulator or parameter space) corresponding to collinear points will intersect at a point. This point defines the slope and intercept of the line through the collinear points. Quantising the slope-intercept space into cells and counting the number of lines crossing each cell, reduces the search for collinear points in the images, to determining the maximum cell in the slope-intercept space.

The HT is one of the most powerful tools in computer vision. Sklansky [10] showed that it provides a result equivalent to that derived by template matching but with less computational effort. The HT thus inherits advantages such as resistance to noise and occlusion. After much research effort, it now has the ability to extract three-dimensional, arbitrary shapes as well as motion parameters [11-13]. Amongst these, a new version of the GHT [12] uses a continuous template description as opposed to the discrete version of the GHT. This has special advantages in cases of rotation and scale.

(A) L3 in frame one. (B) L3 Edge Image in frame one. (C) L3 edge shape in frame one.

Figure 2: Vertebra L3 and its edge in frame 1

In this paper, we first obtained the L3 image shown in Figure 2(A) from a videofluoroscopic image (Figure 1). An edge image was derived, after application of the Matlab Image Toolbox, shown in Figure 2(B). We also obtained the L3 shape by manual extraction, as illustrated in Figure 2(C). Based on the chain code, we obtained the Fourier Descriptors to describe the model shape. Figure 3 shows the model and its 4-, 8- and 16- Fourier coefficients reconstruction. Of these, the 8-descriptor model appears to best match the original data and the extra complexity of the 16-descriptor model does not appear to be required, whereas the 4-descriptor model appears to lack resolution. The Fourier coefficients provide us with a powerful tool to describe the shape analytically, which is then used for arbitrary shape extraction. In this case, the descriptors appear sufficient for vertebral extraction.

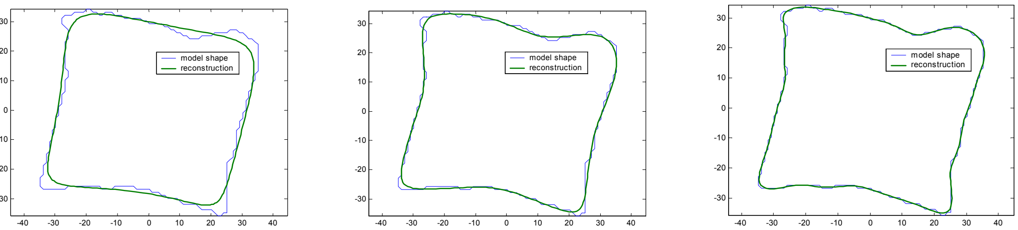

Figure 3: Vertebra L3 model and its 4-, 8- and 16-harmonic reconstruction.

In order to test its validity, we have used our method to extract the manual shape in Figure 2 (C). And we can obtain the expected results, but dependent on numbers of descriptors.

The new HT algorithm was then applied to determine the translation (the *x* and *y* directions), rotation and scale parameters of the vertebra L3. In this case, the Hough space is four-dimensional (4D). Figure 4(A) is one of the parameter spaces with the true scale and rotation angle while 8 descriptors are used. Figure 4(B) and (C) show the results, which were superposed on both the original and the edge image. Here, the 8-descriptor reconstruction gives a good match to the image data, and this is confirmed in the edge data. The match for 4 and for 16 descriptors is shown in Figures 5 (A) and (B), respectively. Visual analysis reveals that 4 descriptors are insufficient, as the result is shifted from its target position, and 16 descriptors are unnecessarily complex as the result is little improved over that for 8 descriptors. For L3 in frame two of the sequence, the same manual model was used, and the final results shown in Figures 6 and 7 were obtained. Clearly, the results are sufficient for a more refined analysis of the match at the vertebral corners, which is the main objective of this approach.

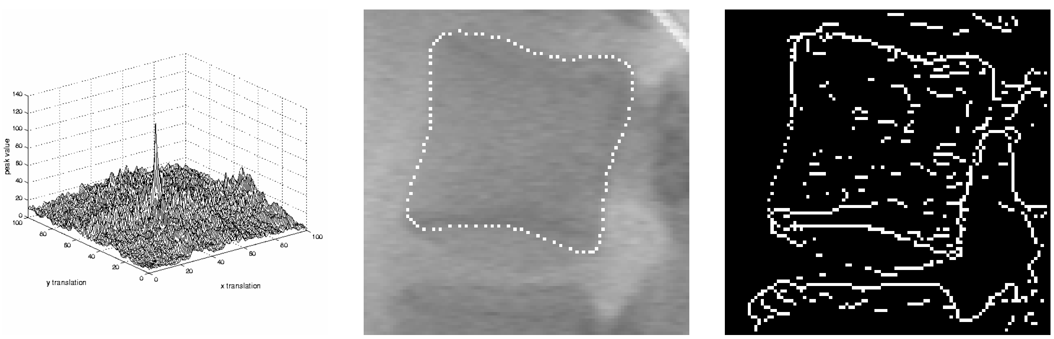

Figure 4: (A) Hough accumulator array. (B) Resulting Extraction using 8 descriptors. (C) Results on edge image.

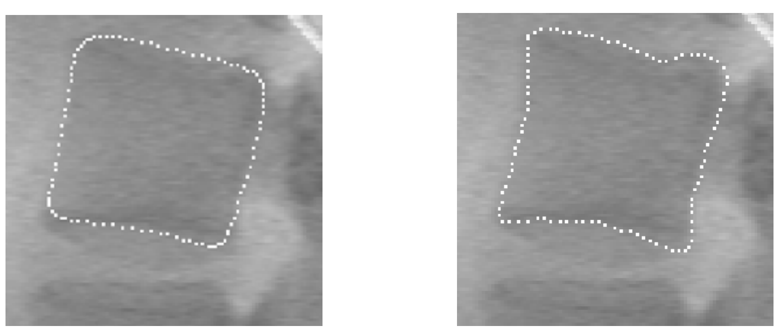

Figure 5: (A) Vertebra L3 Extraction using 4 descriptors. (B) Vertebra L3 Extraction using 16 descriptors.

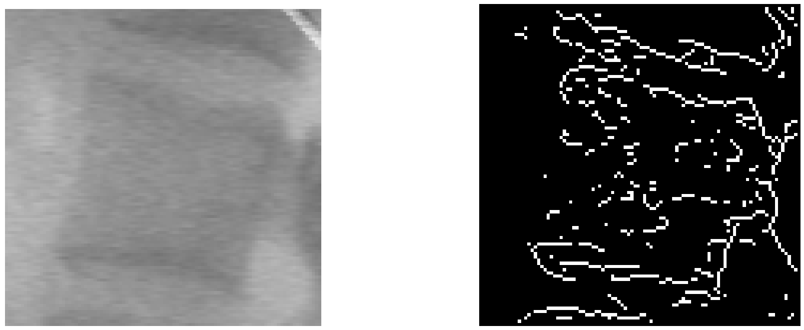

Figure 6: (A) Vertebra L3 in frame two. (B) Vertebra L3 Edge Image in frame two.

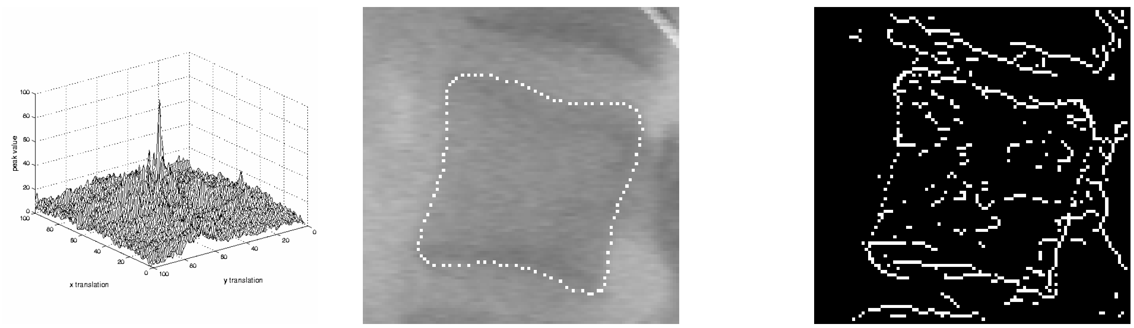

Figure 7: (A) Hough accumulator array. (B) Resulting Extraction on original shape. (C) Results on edge image.

3 Conclusions and Future Work

We have applied a recently developed version of the GHT, which uses a continuous formulation to provide improved performance in rotation and scale, to extract lumbar segments from fluoroscopic images of the spine. This provides us with a useful tool to obtain the parameters even when the object edge is occluded or corrupted by noise. This is essential in spinal motion studies because the images obtained are usually of low quality due to the low radiation dosage. The results suggest that this new HT can provide results of sufficient accuracy for initialising refinement at vertebral corners.

At present, we have used a 4D accumulator space, which has large computational cost. We will improve our algorithm to improve computation time for real-time application so that we can evaluate the performance using a large data set. We will apply this method to other spinal segments to extract their motion parameters. With these parameters, we will determine the kinematics of lumbar in order to shed light on clinical diagnosis and medical understanding of low back pain.

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