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Stabilization of Particle Filter Based Vertebrae Tracking in Lumbar Spinal Videofluoroscopy

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ABSTRACT

Tracking of spinal vertebrae in videofluoroscopy video is useful for diagnosis of certain spine pathologies, such as vertebral fractures, spondylolisthesis and low back pain. The aim of this work is to improve a semi-automatic method for vertebrae tracking based on particle filter. The process starts with vertebrae model construction by splining hand-selected landmark points, then the particle filter tracks the vertebrae in each frame. While the process successfully tracks the vertebras, the trajectories are quite jittery This paper aims to improve the overall tracking by smoothing the tracking trajectory using curve fitting function. The tracking results are more natural with very little noise.

Keywords*:*

Objects tracking, Particle filter, Lumbar vertebrae, Videofluoroscopy, Smoothing.

1. INTRODUCTION

The low back supports the weight of the upper body and provides mobility for everyday motions such as bending and twisting. Muscles in the low back are responsible for flexing and rotating the hips while walking, as well as supporting the spinal column, all those movements could affect intervertebral joint. Hence, the Low Back Pain (LBP) is classified as one of the most common health problems. Researchers in [1] have found that nearly 10% of the world's population (including children) suffers from low back pain and one third of work-related disabilities are due to low back pain. (That is why several studies still deal with this area). In [2] authors demonstrate that irregular motions in one intervertebral joint can affect adjacent joint motion. In [3] a strong relation between the abnormal kinematic behaviour of the lumbar spine and low back pain was proved by using an electromagnetic tracking system. motion irregularities in the lower lumbar spine can produce compensatory effects in the upper lumbar spine [4].

1.1. Medical Imaging

Medical image visualisation- is a helpful tool in disease diagnosis and in monitoring, as well as in surgical and therapeutic guidance [5].

Many techniques have developed to measure the vertebra motion [6] [7] [8] based on vertebrae segmentation [9] [10]. X-rays, the most used imaging technique, provides detailed information about the geometry, aberrant features, and positions of individual vertebrae, but only for select static postures. Videofluoroscopy however, provides similar information to X-rays in real time. It allows vertebral positions to be observed throughout their course of motion. Compared to X-rays, the videofluoroscopy provide less details about geometry and structural anomalies, and it contains noise which is quantum in nature and typically modelled as a Poisson-distribution [11] [12].

A classical examination with videofluoroscopy technique can produce a sequence of hundreds of images, which makes it a challenge to track the motions of vertebrae accurately. The segmentation and the tracking of objects movements is a complex and still an open problem; with many applications as such as video coding, robotics, video surveillance, and medical imaging.

The aim of this work is to improve the vertebrae tracking based on Particle Filter in lumbar spinal videofluoroscopy using a polynomial fit.

1.2. Objects Tracking

The tracking of real-world objects is a challenging problem due to noise, occlusion, and the presence of other moving objects. The main difficulty in video tracking is to associate the location of the targets in the successive frames, especially when the objects move fast relative to the frame rate [13]. The tracking systems normally use a model that describes how the target's image can change considering the possible movements of the tracked object. Many Algorithm have been implemented to surmount these difficulties; they can be classified into two categories: deterministic methods and Probabilistic methods [14].

Deterministic methods are connecting each object in previous frame with single object in current frame using a group of motion characteristics. The characteristics of the objects commonly used are proximity (limited displacement hypothesis) and appearance (similarity of form and / or photometric content and / or motion). In object-based models, targets can be) characterized by color or contour histograms, a contour map (open or closed contour of the object), or a combination of these models. In [15] information on the contours contained in the objects is used to track people. The distance measurement between tracked object and observations is a correlation measure calculated on the contours of the object

Probabilistic methods Observations obtained by a detection algorithm are often corrupted by noise. In addition, the movement or appearance of an object may vary slightly between two consecutive frames. Probabilistic methods allow to manage these variations by adding uncertainty to the model of the object and the models of the observation. The tracking of a single target is then obtained by filtering methods such as Kalman filter or particle filter.

1.3. Related Works

In a previous work [16] authors present a technique to track the vertebrae using particle filters with image gradient based likelihood measurement, Balkovec et al. [17] developed an iterative template matching algorithm to obtain precise time-course details about individual vertebrae and intervertebral motions from videofluoroscopy images.

2. MATERIALS AND METHODS

Poor image contrast, image noise, image distortion, and soft-tissue-induced changes in vertebrae appearance, all those causes make the tracking of individual vertebrae in videofluoroscopy images very challenging. In this paper, we seek to overcome these challenges by following the process below (figure 1)

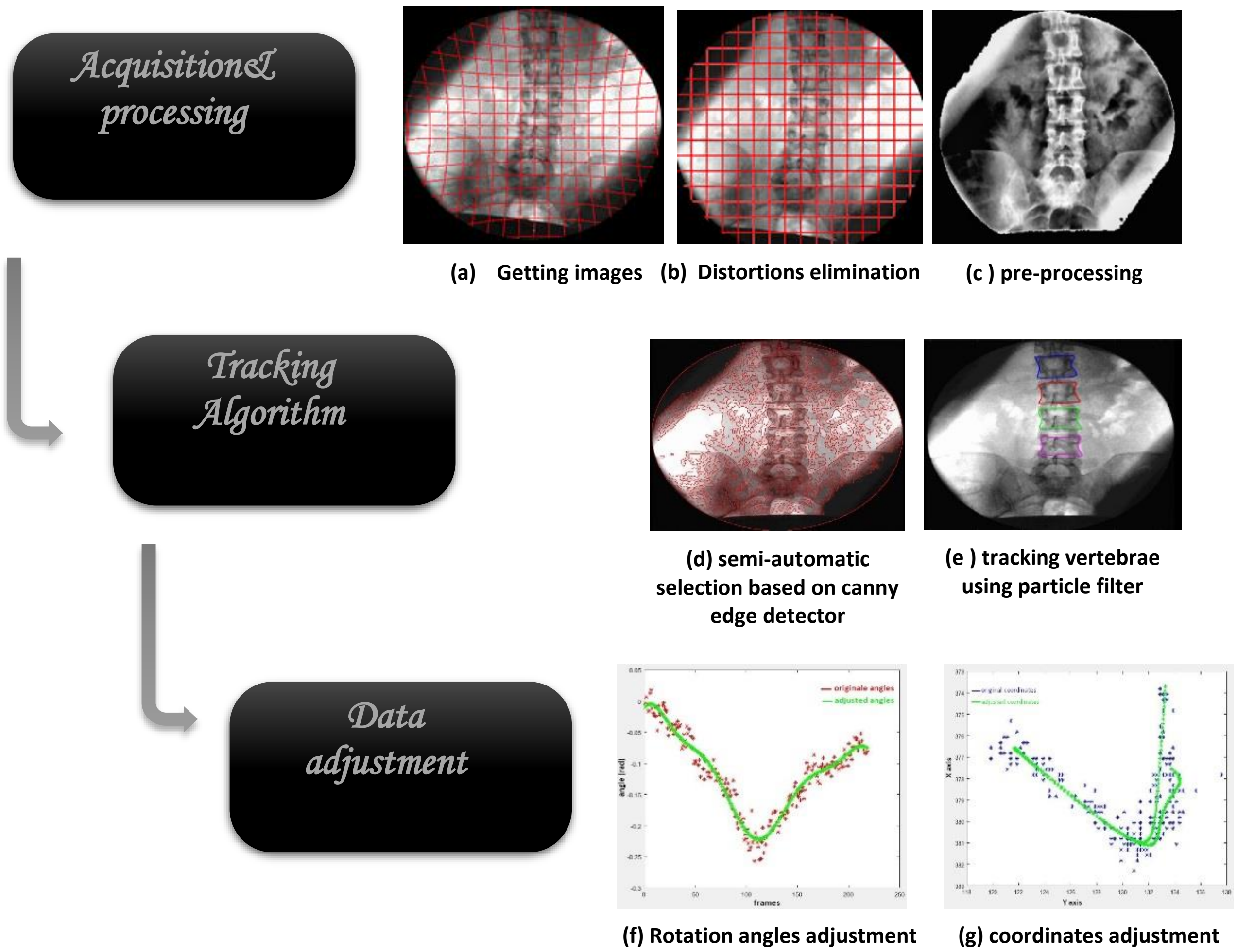

Figure 1. Procedural overview. (a) An image from frontal view. Pincushion distortion is evident in the superimposed red grid lines. (b) Pincushion distortion is removed using an image distortion correction algorithm (Equation 1). (c) The contrast of each image is enhanced with many filtering algorithms. (d) image with superimposed Canny edge detector to help in semi-automatic selection of vertebrae outline. (e) Particle filter tracking phase. (f) Rotation angles adjustment using curve fitting function. (g) The contour centre coordinates adjustment using curve fitting function.

2.1. Image Acquisition and Processing

Image distortion in videofluoroscopy has various sources. [18] pointed out that, in addition to perspective, the curved image intensifier produces 'pin-cushion' distortions [19] where straight lines are curved outwards from the center. The correction method devised in [18] overcomes this problem using a calibration approach. They used a calibration grid composed of wire markers. The grid was placed between the subject and image intensifier and its corners were digitized. Linear correction of object coordinates was then performed within each grid box. pincushion distortion was corrected using the formula:

$$s = r\left(\frac{1}{1 + C\left({}^{r}/_{R}\right)^{2}}\right) \quad (1)$$

Where s is the modified radial distance to a pixel that was at radius r from the center, and R and C are the radius to a corner of the image and the radial distortion coefficient, respectively. To find the radial distortion coefficient C, we start to adjust it until all squares on the grid appeared to be approximately the same size (Figure 1(b)) and the lines across the image are straight, then use it to correct all images.

In the processing step, images were enhanced using an adaptive noise removal filtering, followed by a median filtering and to increase the dynamic range of the histogram, an adaptive histogram equalization was processed.

2.2. Tracking Algorithm

2.2.1. Semi-automatic selection

Semi-automatic video object segmentation approach consists of two steps: interactive initialization and automatic tracking. A system using this strategy therefore comprises two corresponding components. The interactive segmentation in the first frame where the user specifies the contour of a semantic object easily and fast with a computer-aided segmentation tool. The manually segmented frame is then used to initialize the automatic tracking component

In this work, we follow this approach using Canny edge detector as a segmentation tool to detect the edge in the first frame, then the user selects few land marks along the vertebra outline basing on the edge detected by canny, these hand-selected points are then fitted with parametric splines (independently to X and Y coordinates) to form the vertebra contour model.

2.2.2. Particle filter

As mentioned above, particle filter is a probabilistic tracking method based on Bayesian perspective. It estimates the internal states X_k in dynamical systems when partial observations Y_k are made, at any time step k. to define the problem of tracking, consider the evolution of the state sequence $(X_k, k \in N)$ of a target given by:

$$X_k = f_k(X_{k-1}, W_{k-1}) \qquad (2)$$

f_k: nonlinear function of state X_{k-1}, {W_{k-1}, $k \in N$ } is the process noise sequence. the aim is to estimate X_k from measurements

$$Y_k = G_k(X_k, V_k) \qquad (3)$$

G_k: nonlinear function of state X_{k-1}, {V_k, $k \in N$ } is the measurement noise sequence.

According to Bayesian perspective, the tracking problem is to calculate some degree of belief in the state X_k at time k, given the data $Y_{1:k}$ up to time k. Thus, it requires to construct the probability density function $p(X_k| Y_{1:k})$. The prediction stage involves using the system model (1?) to obtain the prior probability density function of the state at time via the equation:

$$p(X_k|Y_{1:k-1}) = \int p(X_k|X_{k-1}) p(X_{k-1}|Y_{1:k-1})\, dX_{k-1} \qquad (4)$$

The probabilistic model of the state evolution $p(X_k|X_{k-1})$ is defined by the system equation (2) and the known statistics of W_{k-1}.

To apply particle filtering for visual tracking, the first issue that needs to be addressed is how to represent the state and the likelihood models, in a previous work [16] authors present a technique to track the vertebrae using particle filters with image gradient based likelihood measurement, the sate of a vertebra model at a time step k is given by $e_k = (x_k; y_k; \theta_k)$ where x_k and y_k are the image coordinates of the contour centre and θ_k is the orientation relative to the centre of mass of the contour.

The likelihood measurement is based on the aggregation of intensity gradient information along each vertebra boundary. The gradient-based likelihood measurement φ(p) is given by:

$$\varphi(x_t^n) = \sum_{n=1}^{N} \frac{Max_{i=1}^{M}\{\gamma_{i,n}\}}{1 + \varepsilon Dn} \qquad (5)$$

where N is the number of normal search line segments, $\gamma_{i,n}$ is the gradient at the ith point/pixel along the line n, D_n is the Euclidian distance between the point with the maximum gradient and the vertebrae contour model, and $\varepsilon = 0.1$ is a weighing factor. Then likelihood is computed as follows:

$$p(y_k|x_k^n) = \frac{\varphi(x_t^n)}{\sum_{n=1}^{N} \varphi(x_t^n)} \qquad (6)$$

2.3. Data Adjustment

2.3.1. Previous results

The proposed tracking technique in the section above is evaluated on a lumbar spinal videofluoroscopy sequences of frontal view.

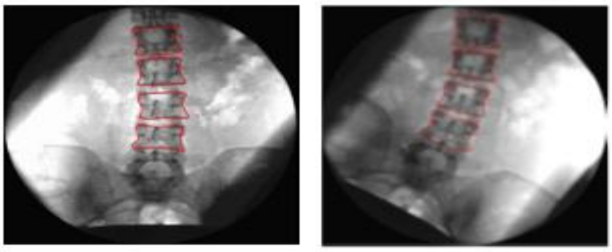

Figure 2. Tracking results for the frontal view with lateral flexion to the right: frames 20 and 100

Using subjective evaluation, the tracking shows good results and all the vertebrae were correctly tracked throughout the sequences (figure 1). To appraise the method objectively, the image coordinates and rotation angles of the contour centre of the second vertebra were recorded and plotted in figures 3 and 4

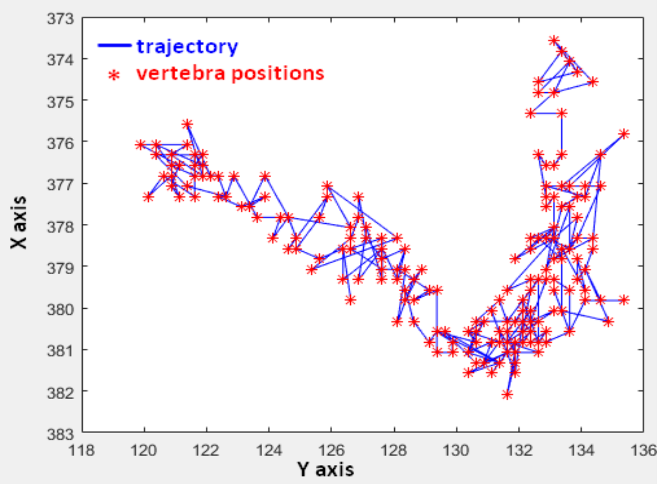

Figure 3. second vertebra trajectory original coordinates

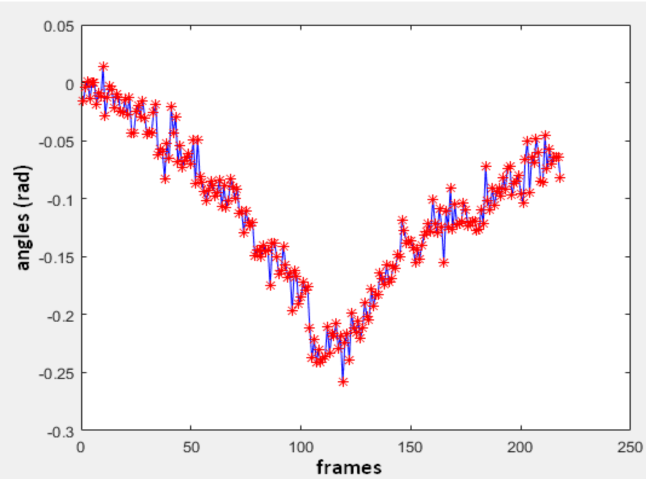

Figure 4. second vertebra trajectory original rotation angles

As it shown on Figure *3* and Figure *4* the vertebrae trajectory is very jittery. (and doesn't give the correct tracking.)

2.3.2. Results Improvement

To make the tracking trajectory appear more naturel, results obtained from the tracking process have been smoothed using a general polynomial fit. Then the centre coordinates and rotation angles of the vertebrae model are adjusted accordingly.

3. RESULTS AND DISCUTION

In this experiment, the performance of the whole system is evaluated. The system ran in the same way as described in 2.2. Firstly, the accuracy on the reported location of the vertebra was tested. One of the vertebra in the video was tracked. The corners will be extracted and reported. Throughout a video sequence of 218 frames was tested. The test results are shown in Figure 3 and Figure 4.

Particle filter based parameters are then recorded and smoothed using the polynomial fitting function., Improved results are shown on Figure 5 and Figure 6. The tracking results of PF can be seen here, while the improved results can be found in here.

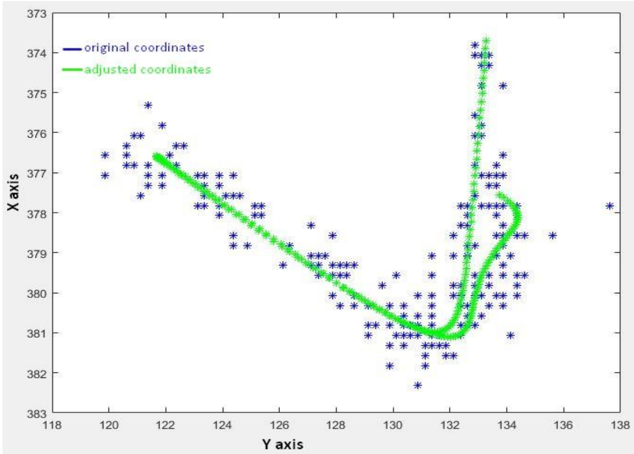

Figure 5. contour centre coordinates adjustment.

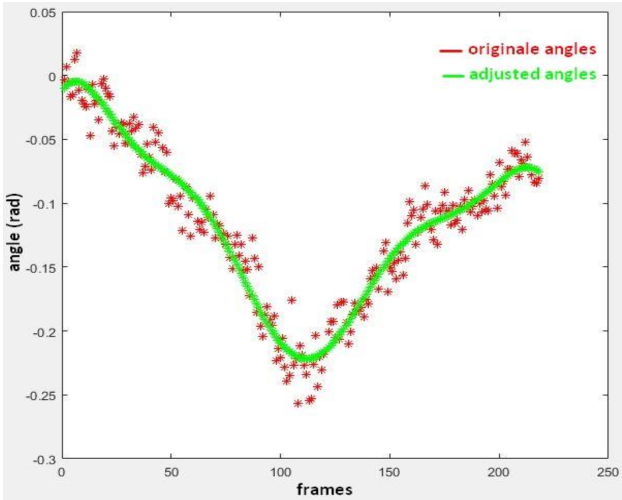

Figure 6. Rotation angles adjustment

4. CONCLUSION

In this paper, we focused on improving lumbar vertebrae tracking using curve fitting function to adjust the trajectory resulted from the particle filter tracking algorithm.

The proposed technique produces more natural and accurate tracking results. While this technique has been used here in the context of vertebrae tracking, we believe that can useful whenever the tracking results are jittery.

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