A Fully Automated New-Fangled VESTAL to Label Cervical Vertebrae and Intervertebral Discs

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Abstract

Spine is a conspicuous part of human body. It encounters a process of changes with age, stress and strain which originates various spinal problems like disc degeneration, disc herniation, and inter vertebral compression. Labeling plays a pivotal role in diagnosing spinal problems. This paper presents a unique method Ve rtebrae Statistics Description Algorithm (VESTAL) to label cervical vertebrae and inter vertebral discs (IVDs). VESTAL uses statistical feature of cervical vertebrae and IVDs. A template is created by VESTAL by determining both posterior, anterior width, heights of cervical vertebrae and IVDs. The template which is formulated will be used for detecting vertebrae and IVDs. This VESTAL application is applied on 45 patients which brought out 225 MR images with 96% accurate results in labeling.

1. Introduction

The vertebral column is the main axis of the human body and it is crucial for supporting the weight of the upper body and shielding the spinal cord [1]. Vertebrae and IVD abnormalities are the major causes of neck pain and lower back pain. The second most common neurological ailment in the world after headache is lower back pain [2]. Most

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of the patients who suffer from this problem are mostly employees, specifically teenagers and middle aged. Hence, cervical area and lumbar area have become salient areas for research. Localization and labeling of the vertebral column its anatomical structures has thus become a focus of recent studies, due to its high demand of analysis specially on the vertebral column and its structures such as disc size, disc shape, and water content percentage in discs which helps to diagnose such problems.

To diagnose spinal problems, radiologists generally label the MR Images manually. Manual labeling is tedious and error prone and it particularly rely upon the expertise of the radiologist. In manual labeling, radiologist labels the vertebrae by identifying one reference point and generally this reference point is known as atlas. Accurate labeling of cervical vertebrae and IVDs are necessary because the backbone has wide variability including degree of bending of the vertebral column, sizes, shapes, and appearances of discs and vertebrae [3]. Figure 1 show a normal and abnormal cervical MR images.

One key issue of labelling is the design of a Computer Aided Diagnosis (CAD) system for cervical and lumbar area. Labelling and segmentation is challenging for a fully automated algorithm since the CT and MR images can be extremely inhomogeneous, neighboring irrelevant structures can be connected and might have similar intensities. A CAD system has been widely utilized based on a variety of modalities such as MRI and CT, assisting physicians in their early detection of various abnormalities such as vertebral fractures, degenerated disc, breast cancers, lung nodules, and intracranial aneurysms [4]. T1 and T2 images are frequently used in diagnosis of spinal images because they provide better contrast between tissues. As a result this study focuses on MR image processing for labelling cervical spine.

Fig 1. (a) Normal MR image; (b) Abnormal MR image
In literature most of the authors proposed methods based on reference points or MR Images in standard position [4, 5]. Many researchers have investigated the problem of labeling the anatomic structures of the vertebral column. However, these studies are limited by their dataset size and thus limit the significance of the validation. The proposed method is based on statistical properties hence named as Vertebrae Statistics Description Algorithm (VESTAL) does not require any reference point, and the image need not be in standard position. VESTAL uses anterior, posterior length and width of cervical vertebrae and based on the relations it labels cervical vertebrae and IVDs by performing the following major tasks.

- Tracing the vertebrae and calculate four corner points for each vertebra using spinal cord path.
- Recognition of vertebrae centre line.
- Localization of the intervertebral disks and
- Labelling cervical vertebrae and IVDs

The rest of the paper is organized as follows: the related work is presented in section 2. Proposed methodology in detailed is given in section 3. Results are presented in section 4. Finally concluding remarks in 5.

2. Related work

Seifert et al. proposed a knowledge-based approach for cervical spine that combines object recognition, segmentation algorithms, and anatomical knowledge is presented for the spine reconstruction from MR images [5]. Srinivas et al., Proposed semi-automatic and fully method to detect discs in spine [6]. Mohammed Benjelloun et al., proposed a semi-automated model called ASM model to detect vertebrae shape [7]. A fully automatic vertebra detection and segmentation system to produce an efficient and effective vertebra detector, a statistical learning approach based on an improved AdaBoost algorithm is proposed by Szu-Hao Huang et al [8]. Yiebin Kim et al., proposed a fully automatic method for vertebra segmentation in the CT volume data. The method constructs 3D fences that separate adjacent vertebrae from valley emphasized Gaussian images [9].

A novel approach for segmenting articulated spine shape models from medical images is introduced by Samuel et al. A nonlinear low-dimensional manifold is created from a training set of mesh models to establish the patterns of global shape variations [10]. Ayse Betul Oktay et al., presented a method for localizing and labeling the lumbar vertebrae and intervertebral discs in mid-sagittal MR image slices [1]. Their approach is based on a Markov-chain-like graphical model of the ordered discs and vertebrae in the lumbar spine. JJ Corso et al., [11], use a graphical model for the lumbar disc localization. Major et al., presented an automated system for land marking and labeling spinal columns in 3D CT datasets [12]. A Hough Transform (HT)-based method to localize discs from video fluoroscopic CT images is proposed by Zheng et al [13].

A two-level probabilistic model for the localization of discs from clinical Magnetic Resonance Imaging (MRI) data that captures both pixel-and object-level features was proposed by Raja et al.,. They used generalized expectation-maximization for optimization, which achieves efficient convergence of disc labels [2]. A framework has been designed by Tobias et al., which takes an arbitrary CT image as input and provides a segmentation in form of labelled triangulated vertebra surface models [14].

Intensity profiles are used by Peng et al., [15] to localize the 24 articulated vertebrae. Schmidt et al., [16] establish a probabilistic inference method that dealings the possible locations of the spinal discs in 3D MR Images. In literature, authors proposed image analysis methods to study about spinal column including vertebra and disc detection, segmentation, and labeling by considering reference point [17-19]. To overcome such drawbacks a novel method VESTAL is proposed.
3. Methodology

The proposed model VESTAL labels cervical vertebrae and IVDs based on threshold values and statistical properties of spinal canal, vertebrae and IVDs. The architecture of the proposed model is shown in figure 2. The phases of the architecture are

![Fig. 2 Architecture of proposed model to label vertebrae and discs](image)

3.1 Spinal canal Detection using canny and modified four connected algorithm

To detect vertebrae and intervertebral discs, the first step is identify spinal canal. Canny operator is applied on MRI image to detect spinal canal. Canny operators is based on the approaches good edge detection, edge localization and only response to each edge. Result of canny contains actual region to be processed for detecting spinal canal. From this result spinal canal is detected using modified four connected algorithm.

**Modified four connected to detect spinal canal**

//IM[][] vector contains threshold values of image 
//IMG[][] vector determines the position of spinal canal 
//p,q intensity ranges of the spinal canal

I=edge(IM,'canny'); // vector I contains required information for processing i.e. for detecting spinal canal

**Algorithm**: searchSpinalCanal(x, y) // works on the region detected by canny

j    =   IM.getPixel(x,y), IMG[m][n]    =    {{0};{0}};
if p<j <q then
begin
    IMG[x][y] =   1
    searchSpinalCanal(x+1, y)
    searchSpinalCanal(x, y+1)
    searchSpinalCanal(x-1, y)
    searchSpinalCanal(x, y-1)
end

The recursive calls can be minimized by processing image in proper order. The generalized equation for spinal canal is

\[ X = A + BY^1 + CY^2 + DY^3 + \cdots \]  \(1\)
The index plays important role. If the index considered for equation increases the efficiency of the spinal cord detection decreases. In experiments better results are obtained using quadratic equation.

### 3.2 Vertebrae and IVD Detection

The result of first step is used for detecting vertebrae. The vertebrae are either left or right to spinal canal. The regions of the spinal canal are searched for detecting vertebrae. While searching these regions features of the vertebrae and IVDs are used. After measuring statistical properties of vertebrae and inter vertebral discs, the average values, deviation from mean values of vertebrae width, height, disc width and height are calculated using the expression 2 and 3

$$\mu = \frac{\sum_{i=1}^{n} Xi}{n}$$  \hspace{1cm} (2)

$$\sigma^2 = \frac{\sum(x - \mu)^2}{n}$$ \hspace{1cm} (3)

**Vertebrae and IVD Detection**

//IM[][] vector contains threshold values of image  
//IMGV[][],IMGIVD[][] vectors contain vertebrae and IVD values  
// m,n: dimensions of image  
//p,q intensity ranges of vertebrae  

**Algorithm**: searchVertebrae()

// randomly chooses a seed pixel(x,y) from spinal canal obtained from searchSpinalCanal()

\[ \text{IMGV}[m][n] = \text{IMGIVD} = \{\{0\};\{0\};\} \]

**while** x>0  // searching for vertebrae in the region left to the spinal canal

**begin**

\[ j = \text{IM}.getPixel(x,y); \]

**if** p< j<q 

**begin**

\[ \text{set IMG}[x][y] = 1; \text{flag}=1; \]

**end**

x=x-1;

**end**

**if** (flag)

**begin**

// vertebrae location may be detected. The coordinates values having specified range used as seed pixel for detecting vertebrae and IVD. To store IVD a separated register can be maintained. If vertebrae is not detected repeat the searchVertebrae() for other seed pixels.

**else**

// search for vertebrae in the region right to the spinal canal

**end**

Vector IMG[] contain pixel flag information. This flag values indicate whether the chosen region contain vertebrae or not. If vertebrae are not detected then x is incremented by appropriate size based on image dimensions of image. This process is continued until vertebrae is detected.
3.3 Features detection and Feature matching

Feature detection and matching are an essential components of many image processing applications. In feature detection phase features of the image like line end points, corner point edges, center of gravity closed regions contours, closed regions intersection point are detected. After detecting the features, determine which features come from corresponding locations in different images. In this phase feature detected from test image are used for correspondence between test image and average features extracted from trained images. Here some mathematical expressions mostly translation, rotation, scaling and combination of these methods are used for proper alignment before matching the properties. Once features and their descriptors are extracted from two or more images, the next step is to establish some preliminary feature matches between these images. The equations for these transformations are given as composite transformation.

\[
\begin{bmatrix}
    r_{sx} \\
    r_{sy} \\
    t_{sx} \\
    t_{sy}
\end{bmatrix} = \begin{bmatrix}
    r_{sx} & r_{sxy} & t_{sx} \\
    r_{syy} & r_{sy} & t_{sy}
\end{bmatrix} \alpha
\]

After aligning images, the template is used for labeling vertebrae and IVD. Using above approaches the complete procedure to detect vertebrae and IVDs consolidated and given in algorithm.

3.3.1 VESTAL Algorithm

a. Creates data base of MRI spine image in uniform size.
b. Sequence of median and Weiner filter followed by image segmentation concepts Region splitting and Region merging are applied to remove noise and irrelevant parts of the image.
c. Detect spinal canal using canny and searchSpinalcanal algorithm
d. Apply fully automated method on filtered images to measure statistical features.
e. Extracted features length, width, and texture from input test image using step 4.
f. Feature matching algorithm is used to label cervical vertebrae and IVDs.

Fully automated method to detect vertebra length, width measurements
// vectors IMGV and IMGIVD contains vertebrae and IVD regions
For each vertebrae region in IMGV calculate lower left, right, upper left and right corner point.
From these values calculate vertebrae anterior width, height, posterior width and height
For each IVD region in IMGIVD calculate left, right, end points and mid height and length.
Create a template by applying above procedure on good number of image

4. Experimental Results

MR Images are magnified to uniform size for accurate measurements. Vertebrae and IVDs locations are detected using spinal canal shape of the spine. The located vertebrae’s width, height average values are measured and these dimensions are scaled to have uniformity in their values and these values are used to plot graphs. Input image and the output of canny edge detection are shown in figure 3.

The relationship between vertebra anterior, posterior width and height of Cervical vertebrae C2 to C7 is given in figure 4. Figures 5 and 6 shows the relation between indivial C2, C3 vertebra’s anterior and posterior width and height. Figures 7 and 8 shows the relation between anterior height and posterior width ranges of cervical vertebraes. Figure 9 shows the poster width relation of vertebraes. The label A specifies anterior width of vertebrae, a1 and a2 specifies the range of this width. The label C specifies posterior width of vertebrae, c1 and c2 specifies the range of this width. The label B anterior height of vertebrae, b1 and b2 specifies the range of this height. The label D posterior height of vertebrae, d1 and d2 specifies the range of this height.
Fig. 3 (a) MRI input Image; (b) Canny edge algorithm result

Fig. 4 Relation between vertebra anterior, posterior width and height of Cervical vertebra C2 to C7

Fig. 5. Relation between range of values of vertebra anterior, posterior width and height of cervical vertebrae C2
Fig. 6. Relation between range of values of vertebra anterior, posterior width and height of cervical vertebra C3

Fig. 7. Relation between anterior height ranges of cervical vertebrae

Fig. 8. Relation between posterior width ranges of cervical vertebrae
The following relations are derived between vertebrae anterior width $A$, height $B$, posterior width $C$ and height $D$ from above results. The relations are given in Table 1.

Table 1. Relation between Statistical Properties

<table>
<thead>
<tr>
<th>S.No</th>
<th>Vertebrae</th>
<th>Derived Relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C2</td>
<td>$C &lt; D$</td>
</tr>
<tr>
<td>2</td>
<td>C3</td>
<td>$B \approx D$</td>
</tr>
<tr>
<td>3</td>
<td>C4</td>
<td>$D = B, C \approx A$</td>
</tr>
<tr>
<td>4</td>
<td>C5</td>
<td>$A &lt; B, C &lt; A, D &lt; A, B &lt; C$</td>
</tr>
<tr>
<td>5</td>
<td>C6</td>
<td>$B &lt; A, B &lt; C, D &lt; A$</td>
</tr>
<tr>
<td>6</td>
<td>C7</td>
<td>$A \approx C, B \approx D$</td>
</tr>
</tbody>
</table>

In Cervical region width of vertebrae is in increasing order from C2 to C6. For C4 vertebrae both heights and widths are almost equal. In Cervical region anterior height and posterior heights are almost equal. The Based on relations derived between $A, B, C,$ and $D$, vertebrae are labeled with 96% accuracy. The values are validated by the orthodomain expert.

5. Conclusions

A unique method VESTAL is proposed to label cervical vertebrae and inter vertebral discs. This algorithm is threshold sensitive consequently quality images are considered for evaluation. The contemplated method uses statistical properties and produces 96% accuracy in labeling vertebral and inter vertebral disc. This labeling is very useful for detecting degenerated disc. In future, this work can be extended for labeling lumber vertebrae which helps in detecting degenerated discs and classification of degenerated discs.
References


