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Human Spine Structure Localization on MRI – A Survey

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Abstract

Objective: This study is mainly to locate all the spine structures on MR Images automatically. Localizing the vertebrae and intervertebral disc is an exacting work due to various different size and shape of the spine in different humans and abnormalities if any. **Methods/Statistical Analysis:** Numerous techniques for localization and labelling on MR images have been proposed during several past years. Identifying spine structures are done using intensity-based models, graphical models like Markov Random Field (MRF), probabilistic models etc. Also, machine learning approaches are used to classify the different structures of the spine. **Findings:** In this paper, a survey is done on different localization algorithms. This paper also describes their key ideas, features, the advantages, and disadvantages. **Application:** Also, it is identified that more future research scope is available in the area of human spine structure localization.

Keywords: Human Spine Structures, Intervertebral Discs, Localization, MR Images Vertebrae

1. Introduction

The human vertebral column is the weight bearing structure of the human body and protects the spinal cord. The human spine structure consists of 33 vertebrae. The human vertebral column is divided into 5 categories as cervical spine, thoracic spine, lumbar spine, sacral spine, and coccygeal spine. The vertebrae are numbered as Cervical – C1 to C7, Thoracic – T1 to T12, and Lumbar – L1 to L5. The sacrum and coccyx do not have numbers and each is considered as a single bone. Each vertebra is separated by Intervertebral Disc (IVD). Each IVD acts as a ligament to hold the vertebrae together and provides a smooth functioning for the vertebral column.

Injury in the vertebral column will affect the whole functionality of the human body. The vertebral column can be viewed by X-rays, Computed Tomography (CT), Magnetic Resonance Image (MRI). In MR images, soft tissues are shown better than X-Rays and CT[1]. Therefore IVDs can be better shown in MR Images. Generally, in the analysis, diagnosis, of the vertebral column the main step is to identify in which spine structure the injury is, i.e., localization and of the spine structures. The radiologists report the diagnosis of the spinal column after labeling the vertebrae and the discs. Any Computer Aided Diagnosis (CAD) system which automatically performs the diagnosis, the analysis on thehuman vertebral column needs the accurate localization (the position of the structures) of the vertebral structures[2]. Therefore automated localization of the spine structures is a major step before doing any analysis of the vertebral column[3]. Figure 1 is a sample of mid-sagittal lumbar MR Image where the vertebrae and IVD are localized and labeled.

A number of techniques have been proposed by various authors for segmentation, and localization of human vertebral column. Papers comparing the segmentation, localization, labeling techniques were also published[4] earlier. Still, a far-reaching survey of localization on MR Images is missing. The main goal of this paper is to collect as much papers as possible, which describes the localization methods for the human vertebral column on MR Images. Section 2 describes graphical models for localization. Section 3 provides details of localization based on intensity. Section 4 discusses probabilistic models. Section 5 concludes the methods of localization of vertebrae on MR Images.

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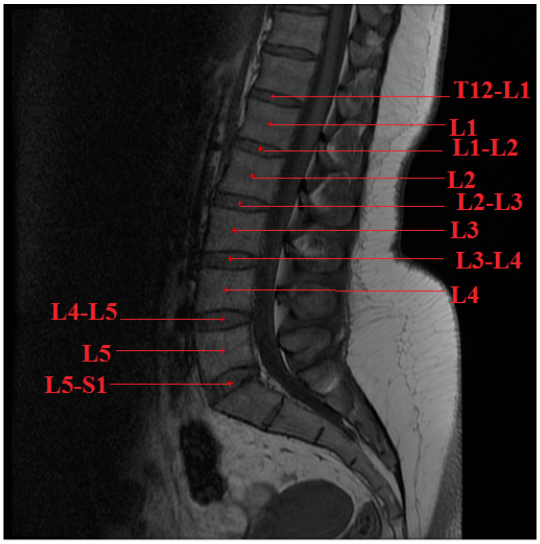

Figure 1. Labeled Lumbar Spine. L1, L2, L3, L4 and L5 are vertebrae. T12-L1, L1-L2, etc are intervertebral disc.

2. Graphical Models

An idea to automize the localization of the lumbar vertebrae and IVDs from 2D sagittal MR Images is presented[2]. The authors of this method mention the two steps. In the first step, the features of the images were extracted using PHOG (Pyramidal Histogram of Gradients) with SVM. This can be improved by including IPD (Image Projection Descriptor) with PHOG. This step is called as image inference. In the second step, the spine is considered as a graphical model called Markov Random Field. The second step is also mentioned as positional inference step as it uses semi-global geometric information and finds the final locations of the structures. A change in one step does not affect the other step. This approach was very efficient with a detection rate of localization as 97.2%. The system can be extended to 3D features, and with combined T1 and T2 weighted MR Image features. This concept was specifically designed for Lumbar vertebrae. The method can also be applied tothe whole human spine. To identify the teeth from X-ray images isanother medical application of this work. Also, this method fails for some images with some abnormalities like lumbarization.

Amethod to extract the vertebral regions from the spinal MR Images for Cervical spine, Thoracic spine, lumbar spine and whole human vertebral column in an automatic manner is discussed[5]. The paper discusses a three stage prototype. The authors mentioned that the vertebra can be detectedmore accurately byusing Ada-Boost based algorithm as the first stage. The second stage is detection refinement via robust curve fitting. The final stage is the vertebrae segmentation. An enhanced Ada-Boost algorithm was developed to detect vertebra from the MR Images. The Ada-Boost constructs a strong classifier from the linear combination of weak classifiers. Then RANSAC (Random Sample Consensus) was applied to fit a spinal curve on the detected vertebra. This eliminates the false detection and recovers the missed detections. An iterative normalized-cut was used for vertebral segmentation. The vertebra detection rate using this method provides an accuracy of 98%. This high level of accuracy was obtained as the iterative normalized-cut considers the intraclass similarity and interclass dissimilarity simultaneously.

Instead of treating vertebrae or IVDs as independent structures, the authors used a hierarchical model[6]. They mentioned a hierarchical learning process and local articulated model to detect vertebrae and IVDs. Also, they carry out a Haar filter based Ada-Boost Algorithm for vertebrae detection. The authors justify good performance on 300 spine MR Images.

3. Intensity based Models

A work for both T1 and T2 weighted mid-sagittal lumbar MR Images was developed[7]. Initially, the spinal cord is extracted. Next, Accurate Region of Interest (AcROI) which is the region between the spinal cord and the left boundary of the vertebral column is extracted. By performing the threshold within this boundary provides the IVDs. This method also works with variations in thickness and slice spacing with an accuracy of 98.8% on disc labeling. The test set consists of 67 images with 335 discs.

In another work[8] the authors discussed automatic vertebra detection and segmentation model for whole spine MR images which uses three procedures. The very first step is the best slice selection. The best MRI slice was selected among all sagittal slices. The slice with the largest number of visible discs and vertebrae is said to be the best slice. The second step is to locate and number all the visible intervertebral discs in the best slice. Also, search for any missing discs in other slices. Canny edge detection algorithm to extract the vertebra boundary is the final step. The advantage of best slice selection is to achieve best detection results and to save the processing time. The work was done on 5 subjects with 7 sagittal images. The accuracy for vertebrae boundary detection is measured for all the subjects and obtained an accuracy of 87.5% on subject 5.

A semi-automatic disc labeling technique was presented in[9]. The top half (Cervicothoracic) and the bottom half (Thoracolumbar) are processed separately. Initially, apply filters to suppress the background noise and histogram processing. Then perform threshold and introduce additional constraints for the region of interest. Always C2-3 intervertebral disc is considered as the centroid for the whole human spine. The system works with 3D MR Images. This model was designed and processed only on adult population. Therefore some modifications are required for the pediatric population.

To determine the imaging plane automatically on lumbar MRI a new methodis designed[10]. The authors suggest 3 steps. Removal of air and subcutaneous fat regions is the first step and is done by histogram analysis, binarization, and morphological filter. Next, it extracts the lumbar vertebrae by using the Sobel filter, binarization, and edge accumulation analysis. Then the determination of slice lines is done by means of binarization, area masking filter, and Hough transform. This suggested method is done for coronal plane MR Image and can be extended to other imaging planes such as axial and sagittal planes. The concordance rate between the automatic determination and manual setting is 90%

The author's in[11] builds a model to detect pathologies in Lumbar MRIs. The research work is to localize the IVDs, to analyze the gray pattern in the disc (to find the injured disc), and verification of findings. They analyze the localization of vertebrae and IVDs in only one MR Image. Intensity profiles and edge detectors were applied as localization methods.

4. Probabilistic Models

Some research works to localize the spine structures also done by a probabilistic approach. One such notable work is by[12]. The researches of this worksuggested a localization method by using two level probabilistic approach for the lumbar spine. They incorporated two levels of information; low-level features and high-level features. Low-level features were local pixel properties of discs, such as appearance, spatial information. Gibbs distribution was used to model these low-level features. Object level features were the geometrical and contextual relationship between discs. These object level features were high-level features and were modeled using spatial distribution. The two level approach was done with the assumption of conditional independence at the low level to improve the efficiency while maintaining the robustness. They obtained about 91% accuracy on training data set and 89% accuracy on the testing data set.

Another research work using done probabilistic approach is[13]. The authors presented a parts based probabilistic graphical model. Their model uses appearance and relative geometry of the pair of parts. For distance measure 1D Gaussian and for location 2D Gaussian was opted. The local information was fused with geometrical information. Then the authors used a heuristic based A* search algorithm, which does a best first greedy coordinate search for efficiency. This part based probabilistic graphical model can be used to localize the whole human spine 3D T1- weighted MR Images. Also Gabor filter and Wavelet transform is used for feature extraction on Lung MR Images[14].

5. Conclusion

Most of the works are done for localization of the whole spine and few for lumbar spine localization. The paper concentrates on three main categories of localization models: Graphical models, intensity-based models, and probabilistic models. The summarizations of the different approaches are done. Also, the most notable differences between the methods are mentioned in this study paper. The advantages and disadvantages are also discussed. It is identified that there is more future scope available to develop a new algorithm for localizing and label the lumbar, cervical and thoracic vertebrae separately.

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