Graduate School of Creative Science and Engineering
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博 士 論 文 概 要
Doctoral Thesis Synopsis

論 文 題 目
Thesis Theme

Deep Learning Based Anatomical Structure Localization and Segmentation in Fetal Ultrasound Images

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Among various medical devices, ultrasonoscopy is the most widely used imaging modality for antenatal examination, because it is harmless to human tissue and can obtain real-time results. The accuracy of ultrasound (US) examination relies on radiologist with years of experience. Lacks of professional training courses could cause to increase the risk of misdiagnose. Moreover, the manpower storage with clinical experience in hospitals is becoming serious issues for many countries all over the world. Thus, to provide more valuable examinations, the working efficiency of doctors needs to be improved by automatic systems. Such automatic system heavily relies on the performance of related medical image processing techniques, which still have gaps with human doctors. Therefore, this thesis aims at providing accurate semantic information of specified anatomical structures for robotic medical care, such as automatic antenatal examination system. To this end, conventional medical image processing methods have drawbacks on accuracy, running speed, etc. On the other hand, with the fast development of deep learning algorithms and hardware acceleration techniques, the computer vision area has achieved great success in recent years. However, deep learning techniques have not yet been fully utilized for medical imaging domain. To solve the above-mentioned issues, this research proposes new deep learning based approaches for analyzing antenatal US images automatically.

The proposals of this thesis are categorized in the following three aspects:

Location of uterus The location and the border of the uterus are important for subsequent processes such as the segmentation of anatomical structures, and the location based guidance of an US probe in automatic medical care systems. Challenges in localizing of uterus from US images include noises and irregular shapes of the target object. The noises may lead to blurred areas in the border of the uterus and incorrect appearances of tissue structures. The uterus has irregular shape because of the non-rigid tissues and different view angles.

Areas of amniotic fluid and fetal body The areas of amniotic fluid and fetal body provide important physiological indexes which can reflect physiology changes in the fetus, and can be used as the guidance of the probe in antenatal examinations. Challenges of the segmentation of the anatomical structure include noises and artifacts in the border areas of the fluid and fetal body. In addition, similar appearance of the body tissue and other tissues such as uterine wall of pregnant women could cause adhesion in adjacent blobs.

Area of fetal head The region of the fetal head provides the fine grained information on the fetal face and brain. The shape and the appearance of the fetal head can be adopted to diagnose fetal hydrocephalus and/or brain tumor. The shape and the position of the fetal head are important for automatic fetal care systems. Such a system requires technologies that locate the fetal head so as to infer the gesture and position of the fetus. It is difficult to determine the classification hyper plane of the slices that include the fetal head, because the appearances of the most of the slices of fetal head are easy to be confused with other fetal body parts such as abdomen slice, etc.

Derived from the above-mentioned issues, the proposed deep learning based approaches target at filling the

blank areas of related tasks in antenatal examinations and optimizing the existing deep learning methods for US image areas. The scheme is separated into the following three modules: 1) bounding box regression Convolutional Neural Network (CNN) for uterus localization, 2) segmentation CNN for semantic segmentation of multiple anatomical structures, and 3) weakly-supervised module for region mining of fetal head.

The proposed methods and the relationship among the three modules are explained below.

1) Bounding box regression CNN for the uterus localization:

The accurate position of the uterus can be used as the region of interest for the subsequent processes such as the semantic segmentation of the anatomical structures. It is difficult to learn shape information from non-rigid objects by handcraft feature descriptors. The existing deep learning based object detectors are mainly used for natural image areas and lack of alignment accuracy. This module proposes a novel method for accurately locating the bounding box of the pregnant uterus in US images.

The proposed deep learning based method utilizes off-the-shelf CNN architecture as the backbone network, and designs a specific regression output structure to regress the candidate positions of the uterus. In particular, to obtain the abundant positions information of the uterus in US image, multiple densely positioned reference boxes are assigned according to the original image. The output of the network is designed as a vector which has same length as the coordinates and confidence of all of the reference boxes. Note that, to enhance the global context information, the output vectors are obtained through linear combination with fully connected weights. During the training phase, the weights of the network are assigned to learn the offsets between pre-defined positions to the ground truth and the confidence of each of the reference box. During the testing phase, the multiple candidate positions of the uterus are regressed by using predicted offset vectors to transfer the pre-defined positions. As the post processing approach, the method seeks the final position by non-maximum suppression to eliminate the redundant candidates.

The proposed uterus localization method is verified using the pregnant US dataset which is collected from clinical examinations. Comparative experiments demonstrate higher detection accuracy than directly using the methods that are to be applied for natural images. Other than that, the method achieves better alignment to the uterus area.

2) Optimized framework for semantic segmentation of multiple anatomical structures:

It is difficult to adopt local feature or cluster analysis based approaches to achieve accurate pixel-wise segmentations in US images. Related deep learning based methods for natural images still have room to improve on segmentation accuracy and smoothness in US images. To provide more accurate and smooth location information of multiple anatomical structures such as the uterus, amniotic fluid and fetal body in pregnant US images, this thesis adopts a deep learning based semantic segmentation framework and proposes specifically designed optimizations.

The segmentation CNN first encodes the input US image into down-scaled feature maps; then adopts the symmetric designed up-scaling operations to map the feature maps back to the original size to perform

pixel-wise classifications. The final predicted masks of multiple anatomical structures are obtained by threshold on the confidence map of each of the categories. Through preliminary experiments on US images, the study finds that the method needs to be further improved for better segmentation accuracy and smooth border areas.

The optimizations for above-mentioned issues are carried out by various ways: 1. The additional inner layers which can enhance the global representations; 2. The usage of the bounding box of the uterus detection which can reduce the data imbalance issue in the pixel-wise classification tasks; and 3. The multiple intermediate supervision layers which can bring obvious improvements to the smoothness of the segmentation blob.

The effectiveness of the proposed approach is evaluated by several different metrics such as IOU (Intersection Over Union), and ROC (Receiver Operating Characteristic) curve of each category on clinical US dataset. Compared with other related deep learning based methods, the proposed method achieves smaller errors to the ground truths (which are manual annotated by doctors with years of experience). In addition, the visualized results demonstrate smoother segmentations by comparing with the baseline methods in US images. The results of this work can be used to accurate reconstructions of fetuses or guidance of an automatic US probe.

3) Weakly-supervised methods for region mining of fetal head:

This module aims at implicitly learning the region of the fetal head based on image level annotations. The existing deep learning based weakly-supervised approaches have defects such as inaccurate localization and incomplete segmentation because of the discriminative area of the used feature level cannot represent the integrated region of the object. Therefore, an optimized method for fetal head plane classification and region mining by learning from image level annotations is proposed. To obtain more complete fetal area than existing works, the study proposes an optimized method which extracts the multiple hieratical feature maps as the discriminative area of the fetal head. In particular, to deal with the issue of incomplete segmentations in US images, a multiple output structure with different feature levels is designed. The proposed weakly-supervised module merges multi-scaled discriminative maps with different feature levels to get more complete salient areas. By means of the proposed multiple output structure, final results are optimized through the combination strategy of multiple discriminative maps.

Comparison experiments are conducted on manual labeled fetal head US slices. Experiments demonstrate the method achieves high classification results and overlapping accuracy. Furthermore, the completeness of the obtained fetal head region is better than conventional related methods.

In summary, first, this thesis has introduced a deep learning based framework for fully supervised uterus detection in US images. Second, the experiments verify the effectiveness of various deep learning based methods for multi-category anatomical structure segmentation and has proposed optimizations for pregnant US images. Furthermore, this thesis has optimized weakly-supervised region mining of fetal head by merging multiple discriminative areas. To verify the gaps between the proposed methods and real-world usages, the performance of each module is compared with human doctors with years of experience. The results are promising that this research makes the development of automatic antennal examinations one step closer to the real world solutions.

早稲田大学　博士（工学）　学位申請　研究業績書

(List of research achievements for application of doctorate (Dr. of Engineering), Waseda University)

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Academic Paper (Reviewed International Conference Papers)	○ Yan LI, Rong Xu, Jun OHYA and Hiroyasu IWATA, “Automatic Fetal Body and Amniotic Fluid Segmentation from Fetal Ultrasound Images by Encoder-Decoder Network with Inner Layers”, EMBC, IEEE Conference on. pp, 1485-1488, (September, 2017) ○ Yan LI, Rong XU, Jun OHYA and Hiroyasu IWATA “Pregnant Uterine Ultrasound Image Segmentation by Encoding-decoding Convolutional neural network”, The 5th IIEEJ International Conference on Image Electronics and Visual Computing (March, 2017)
Academic Paper (Domestic conferences)	Yan LI, Ye LI and Jun OHYA, "Road Vanishing Point Detection by Multi-Stage Convolutional Neural Network", Visual/Media Computing Conference, pp. 1-4, Tokyo, Japan, (June, 2016)