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EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: DEEP LEARNING FOR COMPUTER-AIDED MEDICAL DIAGNOSIS

As neuroimaging scanners grow in popularity in hospitals and institutes, the tasks of radiologists are increasing. Emotion, fatigue, and other factors may influence the manual interpretation of results. This manual interpretation suffers from inter- and intra-radiologist variance. Computer-aided medical diagnosis (CAMD) are procedures in medicine that assist radiologists and doctors in the interpretation of medical images, which may come from CT, X-ray, ultrasound, thermography, MRI, PET, SPECT, etc. In practice, CAMD can help radiologists to interpret medical images within seconds. Conventional CAMD tools are built on top of handcrafted features. Recent progress on deep learning opens a new era in which features can be automatically built from a large amount of data. Many important medical projects were launched during the last decade (Human brain project, Blue brain project, Brain Initiative, etc.) that provide massive amounts of data. This emerging big medical data can support the use of deep learning.

This Special Section aims to provide a forum to present the latest advancements in deep learning research that directly concern the computer-aided diagnosis community. It is especially important to develop deep networks to identify normal-appearing lesions, which may be neglected by human interpretation.

Our Call for Papers received an enthusiastic response with more than 120 high-quality submissions. Per IEEE Access policy, it was ensured that handling editors did not have any potential conflict of interest with authors of submitted articles. All articles were rigorously reviewed by at least two independent referees. The articles were evaluated for their rigor and quality, and also for their relevance to the theme of our Special Section. After a rigorous review process, we accepted 26 articles to form the Special Section.

In the article, "Robust 3D convolutional neural network with boundary correction for accurate brain tissue segmentation," by Hou *et al.* the authors automatically segmented cerebrospinal fluid (CSF), gray matter (GM), and white matter (WM) using multi-modality magnetic resonance scans. A novel coarse-to-fine method was proposed to segment CSF, GM, and WM using two cascade 3D CNNs. The first densely connected fully convolutional network (DC-FCN) was designed with feature reuse, which took full advantage of spatial information and alleviated computer memory limitations. The second 6-CNN was designed to correct boundary voxel, which further reduced computational cost while improving the segmentation accuracy. Their method ranked third in the MRBrainS13 challenge, outperforming most of the participant methods when using available input modalities (T1, T1-IR, and T2-FLAIR).

In the article, "Development of an automated screening system for retinopathy of prematurity using a deep neural network for wide-angle retinal images," by Zhang *et al.* the authors evaluated the performance of a deep neural network (DNN) for the automated screening of retinopathy of prematurity (ROP). The training and test sets came from 420 365 wide-angle retina images from ROP screening. A transfer learning scheme was designed to train the DNN classifier. The labeled training set (8090 positive images and 9711 negative) was used to fine-tune three candidate DNN classifiers (AlexNet, VGG-16, and GoogLeNet) using the transfer learning approach. The resultant classifiers were evaluated on a test dataset of 1742 samples and compared with five independent pediatric retinal ophthalmologists. The receiver operating characteristic (ROC) curve, ROC area under the curve, and precision-recall (P-R) curve on the test dataset were analyzed. The data from the five pediatric ophthalmologists were plotted in the ROC and P-R curves to visualize their performances. VGG-16 achieved the best performance. At the cutoff point that maximized F1 score in the P-R curve, the final DNN model achieved 98.8% accuracy, 94.1% sensitivity, 99.3% specificity, and 93.0% precision. This was comparable to the pediatric ophthalmologists (98.8% accuracy, 93.5% sensitivity, 99.5% specificity, and 96.7% precision). In the screening of ROP using the evaluation of wide-angle retinal images, DNNs had high accuracy, sensitivity, specificity, and precision comparable to that of pediatric ophthalmologists.

In the article, "RIC-Unet: An improved neural network based on Unet for nuclei segmentation in histology images," by Zeng *et al.* a Unet-based neural network, RIC-Unet (residual-inception-channel attention-Unet), for nuclei segmentation was proposed. The residual blocks, multi-scale, and channel attention mechanism techniques were applied on RIC-Unet to segment nuclei more accurately. RIC-Unet was compared with two traditional segmentation methods: CP and Fiji, two original CNN methods: CNN2, CNN3, and original U-net on The Cancer Genomic Atlas (TCGA) dataset. The authors used Dice, F1-score, and aggregated Jaccard index to evaluate these methods. The average of RIC-Unet and U-net on these three indicators were 0.8008 versus 0.7844, 0.8278 versus 0.8155, and 0.5635 versus 0.5462. In addition, their method won third place in the computational precision medicine nuclei segmentation challenge together with MICCAI 2018.

In the article, "Classification of breast cancer histology images using multi-size and discriminative patches based on deep learning," by Li *et al.* the authors extracted both small and large patches from histology images, including cell-level and tissue-level features, respectively. However, there were some sampled cell-level patches that did not contain enough information that matched the image tag. Therefore, the authors proposed a screening method based on the clustering algorithm and CNN to select more discriminative patches. The approach proposed in this article was applied to the 4-class classification of breast cancer histology images and achieved 95% accuracy on the initial test set and 88.89% accuracy on the overall test set. The results were competitive compared to the results of other state-of-the-art methods.

In the article, "Quantitative analysis of immunochromatographic strip based on convolutional neural network," by Zeng *et al.* CNN was applied to the image segmentation of gold immunochromatographic strips. The established CNN network learned the grayscale features of the pre-processed images. Then, the control and test lines were accurately extracted, and further quantitative analysis was performed. The results showed that the method proposed in this article had a good segmentation effect on the GICA, and it also provided a new scheme for the quantitative analysis of the Gold immunochromatographic assay (GICA).

In the article, "AHCNet: An application of attention mechanism and hybrid connection for liver tumor segmentation in CT volumes," by Jiang *et al.* the authors designed an Attention Hybrid Connection Network architecture which combined soft and hard attention mechanisms, and long and short skip connections. The authors also proposed a cascade network based on the liver localization network, liver segmentation network, and tumor segmentation network, to cope with this challenge. Simultaneously, the joint dice loss function was proposed to train the liver localization network to obtain the accurate 3D liver bounding box, and the focal binary cross entropy was used as a loss function to fine-tune the tumor segmentation network for detecting more potentially malignant tumors and reduce false positives. Their framework was trained using the 110 cases in the LiTS dataset and extensively evaluated by the 20 cases in the 3DIRCADb dataset as well as the 117 cases in the Clinical dataset. This indicated that the proposed method could achieve faster network convergence and accurate semantic segmentation, and further demonstrated that the proposed method has good clinical value.

In the article, "Ensembles of patch-based classifiers for diagnosis of Alzheimer diseases," by Ahmed *et al.* the authors' study was confined to structural magnetic resonance imaging (sMRI). The objectives of their attempt were: 1) to increase the accuracy level that is comparable to the state-of-the-art methods, 2) to overcome the overfitting problem, and 3) to analyze proven landmarks of the brain that provide discernible features for AD diagnosis. Here, they focused specifically on both the left and right hippocampus areas. To achieve the objectives, at first, the authors incorporated ensembles of simple CNNs as feature extractors and softmax cross-entropy as the classifier. Then, considering the scarcity of data, they deployed a patch-based approach. Their experiment was performed on the Gwangju Alzheimer's and Related Dementia (GARD) cohort dataset prepared by the National Research Center for Dementia (GARD), Gwangju, South Korea. They manually localized the left and right hippocampus and fed three view patches (TVPs) to the CNN after the preprocessing steps. They achieved 90.05% accuracy.

In the article, "Ensemble of instance segmentation models for polyp segmentation in colonoscopy images," by Kang and Gwak (see also the linked Correction article: xxxx), the authors' research was primarily motivated by the need to obtain an early and accurate diagnosis of polyps in colonoscopy images. In this article, the authors employed a powerful object detection neural network "Mask R-CNN" to identify and segment polyps in colonoscopy images. Also, they proposed an ensemble method to combine two Mask R-CNN models with different backbone structures (ResNet50 and ResNet101) to enhance the performance. Mask R-CNNs in their model were first trained on COCO dataset, and then finely tuned using an intestinal polyp dataset since a large number of annotated colonoscopy images were not easily accessible. In order to evaluate the proposed model, the authors used three open intestinal polyp datasets, CVC-ClinicDB, ETIS-Larib, and CVC-ColonDB. The results show that their transfer learning-based ensemble model significantly outperforms state-of-the-art methods.

In the article, "Automated diabetic retinopathy detection based on binocular siamese-like convolutional neural network," by Zeng *et al.* a computer-aided diagnosis method based on deep learning algorithms was proposed to automatically diagnose referable diabetic retinopathy by classifying color retinal fundus photographs into two grades. A novel CNN model with Siamese-like architecture was trained with a transfer learning technique. Unlike previous works, the proposed model accepted binocular fundus images as inputs and learned their correlation to help to make a prediction. In the case with a training set of only 28 104 images and a test set of 7024 images, an area under the receiver operating curve of 0.951 was obtained by the proposed binocular model, which was 0.011 higher than that obtained by the existing monocular model. To further verify the effectiveness of the binocular design, a binocular model for five-class DR detection was also trained and evaluated on a 10% validation set. The result showed that it achieved a kappa score of 0.829 which was higher than that of the existing non-ensemble model.

In the article, "Triple-classification of respiratory sounds using optimized S-transform and deep residual networks," by Chen, *et al.* a novel method was proposed for the identification of wheeze, crackle, and normal sounds using the optimized S-transform (OST) and deep residual networks (ResNets). First, the raw respiratory sound was processed by the proposed OST. Then, the spectrogram of OST was rescaled for the Resnet. After the feature learning and classification were fulfilled by the ResNet, the classes of respiratory sounds were recognized. This proposed method provided reliable access for respiratory disease-related telemedicine and E-health diagnosis. The experimental results showed that the proposed OST and ResNet was excellent for the multi-classification of respiratory sounds with the accuracy, sensitivity, and specificity up to 98.79%, 96.27% and 100%, respectively. The comparison results of the triple-classification of respiratory sounds indicated that the proposed method outperformed the deep-learning-based ensembling CNN by 3.23% and the empirical mode decomposition-based artificial neural network (ANN) by 4.63%, respectively.

In the article, "Deep convolutional neural networks for WCE abnormality detection: CNN architecture, region proposal and transfer learning," by Lan *et al.* the authors sought to identify a better method for Wireless capsule endoscopy (WCE) abnormal pattern detection. CNNs were used to implement detection function, and several methods were also adopted to boost the performance of WCE abnormality detection from aspects of the CNN architecture, region proposal, and transfer learning. First, the authors presented a deep cascade network, namely, CascadeProposal, trained end-to-end to generate a small number of region proposals with high-recall by a region proposal rejection module, and to simultaneously detect abnormal patterns using a detection module. Second, they used a multiregional combination (MRC) method to obtain good coverage of the regions of interest and employed the salient region segmentation (SRS) method to capture accurate region locations. Third, they used the dense region fusion (DRF) method for object boundary refinement. Fourth, they introduced negative category (Neg) and transfer learning (TL) strategies into CNNs to obtain a better model performance. The extensive experiments were performed on their WCE image dataset of more than 7k annotated images. A final mean average precision (mAP) of 70.3% and a better mAP of 72.3% were achieved via CascadeProposal with ZF and Fast R-CNN with VGG-16 networks, respectively, using the MRC+Neg+TL method in the training stage and the MRC+DRF+SRS method in the testing stage. The comprehensive results demonstrated that their method was efficient and effective for WCE abnormality detection with high-localization accuracy.

In the article, "Boundary delineation of MRI images for lumbar spinal stenosis detection through semantic segmentation using deep neural networks," by Al-Kafri *et al.* the authors proposed a methodology to aid clinicians in performing lumbar spinal stenosis detection through semantic segmentation and delineation of magnetic resonance imaging (MRI) scans of the lumbar spine using deep learning. They developed a ground truth dataset containing image labels of four important regions in the lumbar spine, to be used as the training and test images to develop classification models for segmentation. They developed two novel metrics, namely confidence and consistency, to assess the quality of the ground truth dataset through a derivation of the Jaccard Index. They experimented with semantic segmentation of their dataset using SegNet. The evaluation of the segmentation and the delineation results showed that their proposed methodology produced a very good performance as measured by several contour-based and region-based metrics. The authors also presented two representative delineation results of the worst and best segmentation based on their BF-score to show visually how accurate and suitable the results were for computer-aided-diagnosis purposes.

In the article, "A deep learning approach for breast invasive ductal carcinoma detection and lymphoma multi-classification in histological images," by Brancati *et al.* the authors explored deep learning methods for the automatic analysis of Hematoxylin and Eosin-stained histological images of breast cancer and lymphoma. In particular, a deep learning approach was proposed for two different use cases: The detection of invasive ductal carcinoma in breast histological images and the classification of lymphoma sub-types. Both use cases had been addressed by adopting a residual CNN that is part of a convolutional autoencoder network (i.e., FusionNet). The performances had been evaluated on the public datasets of digital histological images and had been compared with those obtained by using different deep neural networks (UNet and ResNet). Additionally, comparisons with the state of the art had been considered, in accordance with different deep learning approaches. The experimental results showed an improvement of 5.06% in F-measure score for the detection task and an improvement of 1.09% in the accuracy measure for the classification task.

In the article, "RP-Net: A 3D convolutional neural network for brain segmentation from magnetic resonance imaging," by Wang *et al.* the authors proposed a 3D CNN including recursive residual blocks and a pyramid pooling module (RP-Net) for segmenting brain from 3D magnetic resonance (MR) images into white matter (WM), gray matter (GM), and cerebrospinal fluid (CSF). RP-Net was a U-Net like the network that consisted of a downsampling path and an upsampling path. All layers in RP-Net were implemented in a 3D manner. The pyramid pooling module was applied before a voxel-wise classification layer for obtaining both local and global context information. The RP-Net had been evaluated on WM, GM, and CSF segmentation with CANDI, IBSR18, and IBSR20 dataset. The experiments showed that the RP-Net achieved mean dice similarity coefficients of 90.7% on CANDI, 90.49% on IBSR18, and 84.96% on IBSR20. The results demonstrated that the proposed method achieved a significant improvement in segmentation accuracy compared to other reported approaches.

In the article, "Pulmonary nodule detection in volumetric chest CT scans using CNNs-based nodule-size-adaptive detection and classification," by Wang *et al.* the authors proposed a simple yet effective CNNs-based classifier for FP reduction, which benefited from the candidate detection. The performance of the proposed nodule detection was evaluated on both independent and publicly available datasets. The detection could reach high sensitivity with few FPs and it was comparable with the state-of-the-art systems and manual screenings. The study demonstrated that excellent candidate detection played an important role in the nodule detection and could simplify the design of the FP reduction. The proposed candidate detection was an independent module, so it could be incorporated with any other FP reduction methods. It could also be used as a potential solution for other similar clinical applications.

In the article, "Nested dilation network (NDN) for multi-task medical image segmentation," by Wang *et al.* the authors proposed a nested dilation network (NDN) which was applied to multiple segmentation tasks for different modalities, including CT, magnetic resonance imaging (MRI), and endoscopic images. The authors designed residual blocks nested with dilations (RnD Blocks) thatcaught a larger receptive field in the first few layers to boost shallow semantic information. They applied the modified focal loss to help the network to provide more accurate segmentation results. They evaluated their method based on five subtasks from medical segmentation decathlon challenge and GIANA2018, and the results showed that their method achieved a better performance than the latest methods in each task.

In the article, "A novel deep arrhythmia-diagnosis network for atrial fibrillation classification using electrocardiogram signals," by Dang *et al.* the authors proposed a novel deep arrhythmia-diagnosis method, named deep CNN-BLSTM network model, to automatically detect AF heartbeats using ECG signals. The model mainly consisted of four convolution layers: Two BLSTM layers and two fully connected layers. The datasets of RR intervals (called set A) and heartbeat sequences (P-QRS-T waves, called set B) were fed into the above-mentioned model. Most importantly, the proposed approach achieved favorable performances with an accuracy of 99.94% and 98.63% in the training and validation set of set A, respectively. In the testing set, the authors obtained an accuracy of 96.59%, a sensitivity of 99.93%, and a specificity of 97.03%.

In the article, "A novel approach for multi-label chest X-ray classification of common thorax diseases," by Allaouzi *et al.* the authors sought to improve the performance of the CAD system in the task of thorax disease diagnosis by providing a new method that combined the advantages of CNN models in image feature extraction with those of the problem transformation methods in the multi-label classification task. The experimental study was tested on two publicly available CXR datasets, ChestX-ray14 (frontal view), and CheXpert (frontal and lateral views). The results showed that the proposed method outperformed the current state of the art.

In the article, "A fast fractal based compression for MRI images," by Liu *et al.* a fast fractal-based compression algorithm for MRI images was proposed. First, three-dimensional (3D) MRI images were converted into a two-dimensional (2D) image sequence, which facilitated the image sequence based on the fractal compression method. Then, range and domain blocks were classified according to the inherent spatiotemporal similarity of 3D objects. By using self-similarity, the number of blocks in the matching pool was reduced to improve the matching speed of the proposed method. Finally, a residual compensation mechanism was introduced to achieve compression of MRI images with high decompression quality. The experimental results showed that compression speed was improved by 2-3 times, and the PSNR was improved by nearly 10. It indicated the proposed algorithm was effective and solved the contradiction between high compression ratio and high quality of MRI medical images.

In the article, "Multi-classification of brain tumor images using deep neural network," by Sultan *et al.* a DL model based on a CNN was proposed to classify different brain tumor types using two publicly available datasets. The former one classified tumors (meningioma, glioma, and pituitary tumor). The other differentiated between the three glioma grades (Grade II, Grade III, and Grade IV). The datasets included 233 and 73 patients with a total of 3064 and 516 images on T1-weighted contrast-enhanced images for the first and second datasets, respectively. The proposed network structure achieved a significant performance with the best overall accuracy of 96.13% and 98.7%, respectively, for the two studies. The results indicated the ability of the model for brain tumor multi-classification purposes.

In the article, "Accurate gastric cancer segmentation in digital pathology images using deformable convolution and multi-scale embedding networks," by Sun *et al.* the researchers used a DL based method and integrated several customized modules. Structurally, they replaced the basic form of convolution with deformable and Atrous convolutions in specific layers in order to adapt to the non-rigid characters and a larger receptive field. They took advantage of the Atrous Spatial Pyramid Pooling module and encoder-decoder based semantic-level embedding networks for multi-scale segmentation. In addition, they proposed a lightweight decoder to fuse the contexture information, and utilized the dense upsampling convolution for boundary refinement at the end of the decoder. Sufficient comparative experiments were enforced on their own gastric cancer segmentation dataset, which was delicately annotated to pixel-level by medical specialists. The quantitative comparisons against several prior methods demonstrated the superiority of the proposed approach, which achieved 91.60% for pixel-level accuracy and 82.65% for mean Intersection over Union.

In the article, "Transfer learning with intelligent training data selection for prediction of Alzheimer's disease," by Khan *et al.* the researchers attempted to solve AD detection with transfer learning, where the state-of-the-art VGG architecture was initialized with pre-trained weights from large benchmark datasets consisting of natural images. The network was then fine-tuned with layer-wise tuning, where only a pre-defined group of layers were trained on MRI images. To shrink the training data size, image entropy was employed to select the most informative slices. Through experimentation on the ADNI dataset, the authors showed that with a training size of 10 to 20 times smaller than the other contemporary methods, they reached the state-of-the-art performance in AD vs. NC, AD vs. MCI, and MCI vs. NC classification problems, with a 4% and a 7% increase in accuracy over the state-of-the-art for AD vs. MCI and MCI vs. NC, respectively. They also provided a detailed analysis of the effect of the intelligent training data selection method, changing the training size, and changing the number of layers to be fine-tuned. Finally, they provided class activation maps (CAM) that demonstrated how the proposed model focused on discriminative image regions that were neuropathologically relevant and could help healthcare practitioners in interpreting the model's decision-making process.

In the article, ''Liver semantic segmentation algorithm based on improved deep adversarial networks in combination of weighted loss function on abdominal CT images,'' by Xia *et al.* an improved model based on the basic framework of DeepLab-v3 was proposed, and Pix2pix network was introduced as the generation adversarial model. The proposed model realized the segmentation framework combining deep features with multi-scale semantic features. In order to improve the generalization ability and training accuracy of the model, this article proposed a combination of traditional multi-classification cross-entropy loss function with the content loss function of generator output and the adversarial loss function of discriminator output. A large number of qualitative and quantitative experimental results showed that the performance of the proposed semantic segmentation algorithm was better than the existing algorithms, and could improve the segmentation efficiency while ensuring the space consistency of the semantics segmentation for abdominal CT images.

In the article, ''Design and application of a laconic heart sound neural network,'' by Cheng *et al.* the authors proposed a laconic heart sound neural network (LHSNN). First, they proposed three requirements. Then, the specific implementation method of the LHSNN was given. Finally, the PhysioNet/CinC Challenge 2016 public heart sound database was used as the experimental object in order to establish a heart sound spectrum library. The experimental results showed that the LHSNN could obtain a recognition rate of 96.16%, a modify accuracy of 0.8950, and could also run on mobile terminals. In addition, the LHSNN was proven to be adaptable by using the open heart sound dataset of the University of Catania. The research in this article had positive significance for the classification and recognition of heart sounds in the natural environment.

In the article, ''Deep learning-based Parkinson's disease classification using vocal feature sets,'' by Gunduz, the author proposed two frameworks based on CNNs to classify Parkinson's Disease (PD) using sets of vocal (speech) features. While the first framework combined different feature sets previously given to 9-layered CNN as inputs, the second framework passed feature sets to the parallel input layers which were directly connected to convolution layers. Thus, deep features from each parallel branch were extracted simultaneously before combining in the merge layer. Proposed models were trained with datasets taken from the UCI Machine Learning repository, and their performances were validated with Leave-One-Person-Out Cross Validation (LOPO CV). Due to imbalanced class distribution in the data, F-Measure and Matthews Correlation Coefficient metrics were used for the assessment along with accuracy. Experimental results showed that the second framework seemed to be very promising, since it was able to learn deep features from each feature set via parallel convolution layers. The extracted deep features were not only successful at distinguishing PD patients from healthy individuals, but were also effective in boosting the discriminative power of the classifiers.

In the article, ''A general common spatial patterns for EEG analysis with applications to vigilance detection,'' by Yu *et al.* the authors extended the traditional common spatial pattern (CSP) to the general version and proposed nonparametric CSP (NCSP) algorithms which did not explicitly rely on the assumption of the underlying class Gaussian distribution. The authors then developed a new efficient algorithm based on matrix deflation to solve the proposed NCSP algorithm and its extensions-nonparametric multi-class CSP (NMCSP). Experimental results on EEG-based vigilance estimation and motor imagery recognition tasks demonstrated the effectiveness and efficiency of the proposed algorithms.

To conclude, we would like to sincerely thank all the authors who submitted articles to our Special Section, and the large number of reviewers who kindly volunteered their time and expertise to help us curate a high-quality Special Section on this important and timely topic. We greatly appreciate the contributions of the reviewers for their constructive comments and suggestions. We would also like to thank IEEE ACCESS Editor-in-Chief and other staff members of IEEE ACCESS for their continuous support and guidance.

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