Guest Editorial:
Special Issue on Imaging-Based Diagnosis of COVID-19

I. INTRODUCTION

THE novel coronavirus 2019 (COVID-19) began infecting humans in late 2019 and then turned into pandemic in the successive months spreading all over the world. At the beginning of July 2020, the global number of confirmed cases reported by the World Health Organization is above 10 million, with more than half million deaths and a rate of new cases of almost 150 000 per day.

The current diagnosis of COVID-19 is based on real-time reverse-transcriptase polymerase chain reaction (RT-PCR), which is considered as the gold standard for confirmation of infection. However, the sensitivity of this diagnostic methodology is low, especially at the initial presentation of COVID-19. On the other hand, medical imaging, such as Computed Tomography (CT), Chest X-ray (CXR), and Lung Ultrasound (LUS), plays a major role in confirming and staging positive COVID-19 patients. For this reason, many research groups in the field of medical imaging have turned their research interests toward the development of new techniques for automated infection measurement and COVID-19 diagnosis from imaging data.

This Special Issue of IEEE TRANSACTIONS ON MEDICAL IMAGING timely collects the top-notch research efforts on this topic. To achieve this goal, the call for paper was organized in two phases: 1) a fast track phase, gathering articles submitted up to April 12, 2020 and characterized by very strict review times, for both authors and reviewers; and 2) a regular phase, reserved to manuscript arriving after the above deadline and accepted on a rolling basis.

This Special Issue received a large interest from the scientific community, i.e., 167 manuscripts were submitted and 12 articles were finally selected for publication. Each article was carefully reviewed by 3-4 experts in the field and went through a rigorous review process, composed of typically two rounds of revisions.

The large majority of articles (9 out of 12) propose methods for the analysis of chest CT scans, with particular reference to the problem of distinguishing between COVID-19 and other pneumonia, e.g., community acquired pneumonia (CAP) and interstitial lung disease (IDL) [item 1) in the Appendix]–[item 5) in the Appendix], of COVID-19 lesion segmentation

[item 6) in the Appendix]–[item 8) in the Appendix] , and of accurate lung lobe segmentation [item 9) in the Appendix]. Among the remaining articles, one proposes methodologies to analyze LUS sequences [item 10) in the Appendix] and another considers CXR images [item 11) in the Appendix]. The last article [item 12) in the Appendix] describes a camera-based automatic positioning system to reduce the physical contact time of technicians with a patient during the COVID-19 pandemic.

In the following Section, we provide key elements of each of the manuscripts included in this Special Issue.

II. ARTICLES INCLUDED IN THE SPECIAL ISSUE

Wang *et al.* in their article entitled "Prior-Attention Residual Learning for More Discriminative COVID-19 Screening in CT Images" [item 1) in the Appendix] propose a framework for fast COVID-19 screening in 3D chest CT images, which allows to reveal the presence of pneumonia and, in case, to determine whether it is caused by COVID-19 or by other viruses. To this aim, the authors fuse two 3D-ResNets into a single model by introducing a novel prior-attention strategy, based on a block named as prior-attention residual learning (PARL). In the proposed architecture, one network is trained to determine the lesion areas within the lungs; this information is then used by the other network to learn discriminative representations for the pneumonia-type classification. The performance of the proposed approach was assessed on the dataset collected by the authors, including the CT scans of 4657 patients, including roughly 20% negative cases, 30% COVID-19 positive cases, and the remaining 50% cases with interstitial lung disease caused by other viruses. The proposed approach compares favorably with respect to other tested architectures, achieving 93.3% accuracy on COVID-19 class.

Han *et al.* in their contribution "Accurate Screening of COVID-19 Using Attention-Based Deep 3D Multiple Instance Learning" [item 2) in the Appendix] propose a novel attention-based deep 3D multiple instance learning (AD3D-MIL) to classify CT scans into three classes, i.e., COVID-19, common pneumonia, and no pneumonia. The authors collected 460 chest CT examples, with 230 CT samples obtained from 79 patients with COVID-19, 100 CT samples from 100 patients with common pneumonia, and 130 CT samples

from 130 people without pneumonia. It is reported an overall accuracy of 97.9% for the proposed method on the collected dataset.

Ouyang *et al.* in their article [item 3) in the Appendix] entitled "Dual-Sampling Attention Network for Diagnosis of COVID-19 From Community Acquired Pneumonia" propose a 3D CNN network for the discrimination between COVID-19 and CAP from chest CT images. The proposed network, which includes both online attention refinement and dual-sampling strategy, achieves roughly 88% accuracy on a very large multi-center (8 hospitals) CT scans dataset composed by 3389 COVID-19 images from 2565 patients and 1593 CAP images from 1080 patients.

Kang *et al.* in the article [item 4) in the Appendix] entitled "Diagnosis of Coronavirus Disease 2019 (COVID-19) With Structured Latent Multi-View Representation Learning" conduct the diagnosis of COVID-19 with a series of features extracted from CT images, which were used as the base to learn a unified latent representation, and successively provided as input to fully connected neural networks. The experimental validation carried out on a dataset with 2522 CT images ($\sim 60\%$ CAP cases, 40% COVID-19) demonstrates that the proposed approach is able to achieve very high accuracy with 95.5%.

The article entitled "A Weakly Supervised Framework for COVID-19 Classification and Lesion Localization From Chest CT" [item 5) in the Appendix] by Wang *et al.* describes a deep learning-based model for automatic COVID-19 diagnosis on chest CT. The proposed method first segments the lung region in CT images using a pretrained U-Net, and then uses a 3D deep network to estimate the probability of COVID-19 infection from the segmented image. Finally, it localizes the COVID-19 lesions using a class activation mapping method. The experimental validation was carried out on a dataset collected by the authors comprising 630 CT volumes. A remarkable feature of the proposed method is that it is able to process a whole CT volume in less than 2 seconds on a consumer GPU.

Fan *et al.* in their article [item 6) in the Appendix] entitled "Inf-Net: Automatic COVID-19 Lung Infection Segmentation from CT Images" propose a novel deep neural network named Inf-Net for the automatic segmentation of lung infection due to COVID-19 from chest CT images. Inf-Net uses a parallel partial decoder to aggregate the high-level features and generate a global map. The representation is also enriched with boundary cues that are modeled by means of the implicit reverse attention and explicit edge-attention. Furthermore, in order to cope with the scarcity of labeled data, the authors also propose a semi-supervised segmentation framework based on a randomly selected propagation strategy. Validated on images collected from publicly available datasets, the proposed approach compares favorably concerning many U-Net variants.

In the article "A Rapid, Accurate and Machine-Agnostic Segmentation and Quantification Method for CT-Based COVID-19 Diagnosis" [item 7) in the Appendix], Zhou *et al.* propose a method that can segment and quantify the regions of infection due to COVID-19 on CT scans. The method introduces a dynamic model to simulate CT scans of the same patient at different time points for data augmentation.

To prevent overfitting, the approach decomposes the 3D segmentation problem into three 2D ones, with a dramatic decrease of the model complexity and a significant increase in the segmentation accuracy. The experimental analysis demonstrates that the method is able to achieve very good and stable performance on a dataset of images collected from different countries and hospitals and using various machines.

Wang *et al.* in the article entitled "A Noise-Robust Framework for Automatic Segmentation of COVID-19 Pneumonia Lesions From CT Images" [item 8) in the Appendix] propose a novel COVID-19 pneumonia lesion segmentation network (COPLE-Net) designed to deal with the lesions with various scales and appearances. Further contributions are represented by the adoption of a noise-robust Dice loss and a framework with adaptive self-ensembling. The experimental analysis was carried out using a dataset of CT scans from 558 pneumonia patients with COVID-19 collected from 10 different hospitals and demonstrated the effectiveness of the proposed approach.

In the article "Relational Modeling for Robust and Efficient Pulmonary Lobe Segmentation in CT Scans" [item 9) in the Appendix], Xie *et al.* present a novel method using relational two-stage convolution neural networks for segmenting pulmonary lobes in CT images. Motivated by the intuition that, for an accurate delineation of pulmonary lobes in case of COVID-19 disease, it is important to consider the structural relationship among the lobes and the surrounding structures such as vessels, airways, and the pleural wall, and thus the authors propose a deep network that is able to capture visual and geometric correspondence between high-level convolution features. Interestingly, the non-local module presented in the article can be easily used for other computer vision tasks such as object detection and recognition. The approach's performance was assessed on a dataset of 470 CT scans from Radboud University Medical Center, Nijmegen, the Netherlands.

In the manuscript "Deep Learning for Classification and Localization of COVID-19 Markers in Point-of-Care Lung Ultrasound" [item 10) in the Appendix], Roy *et al.* propose a study regarding the application of the deep learning methodologies for the analysis of lung ultrasonography (LUS) images. They introduce a novel deep network derived from spatial transformer networks, which predicts the disease severity score associated with an input frame and localizes pathological elements in a weakly supervised way. Then, results obtained on each frame are aggregated at video level by a new method based on uninorms. They also present a comparative study of state-of-the-art deep models for estimating pixel-level segmentations of COVID-19 imaging biomarkers. The experimental validation is done using a novel fully annotated dataset of LUS images collected from five hospitals in Italy. The ICLUBS-DB (Italian COVID-19 Lung Ultrasound DataBase) includes 277 LUS videos from 35 patients (49% COVID-19 positive, 11% COVID-19 suspected).

In the manuscript "Deep Learning COVID-19 Features on CXR Using Limited Training Data Sets" [item 11) in the Appendix], Oh *et al.* find that the globally distributed localized intensity variation can be a discriminatory feature for the detection of COVID-19 signs in chest X-rays.

Consequently, they propose and train a patch-based deep neural network architecture. At the same time, the final decision is made based on the majority voting from multiple patches at random locations within the lungs. The main achievement is that the proposed approach can provide comparative results with another state-of-the-art methods that require a large dataset to obtain a stable training.

Karanam *et al.* in their article "Towards Contactless Patient Positioning" [item 12) in the Appendix] presents their experience in the design and implementation of a system that allows remotely scanning a patient and eliminating all physical contacts with the aim of reducing the likelihood of medical professionals getting infected. The authors propose a detailed description of all components of the system, and conduct extensive experimentation on the public and proprietary datasets that demonstrated the effectiveness of the approach which can be also extended to non-pandemic scenarios.

III. Conclusion

The preparation of the Special Issue has given us a sound confirmation of the considerable interest and the prompt response given by the scientific community of the medical imaging to this very compelling problem, and of the high quality of the research carried out by the groups working to solve it. We hope this Special Issue will meet the interest and the appreciation of the readers and might be essential for the clinical practice by providing tools that can alleviate and support the work of the medical doctors during this pandemic and in the future.

The realization of this Special Issue represented a challenging but simultaneously stimulating challenge for all the editorial group because of the very high number of received submissions and tight deadlines set for it.

Finally, we thank the reviewers for their timely and professional comments. We are also very grateful to the Editor in Chief of the IEEE Transactions on Medical Imaging, Prof. Leslie Ying, for giving us the opportunity for this publication and for her guidance. A special thank is dedicated to the Managing Editor of the journal, Prof. Rutao Yao, for his timely and robust support. Most importantly, thanks to all the authors who submitted their manuscripts to this Special Issue, making it a success.

Appendix
Related Works

1) J. Wang *et al.*, "Prior-attention residual learning for more discriminative COVID-19 screening in CT images," *IEEE Trans. Med. Imag.*, early access, May 15, 2020, doi: 10.1109/TMI.2020.2994908.
2) Z. Han *et al.*, "Accurate screening of COVID-19 using attention based deep 3D multiple instance learning," *IEEE Trans. Med. Imag.*, early access, May 21, 2020, doi: 10.1109/TMI.2020.2996256.
3) X. Ouyang *et al.*, "Dual-sampling attention network for diagnosis of COVID-19 from community acquired pneumonia," *IEEE Trans. Med. Imag.*, early access, May 18, 2020, doi: 10.1109/TMI.2020.2995508.
4) H. Kang *et al.*, "Diagnosis of coronavirus disease 2019 (COVID-19) with structured latent multi-view representation learning," *IEEE Trans. Med. Imag.*, early access, May 6, 2020, doi: 10.1109/TMI.2020.2992546.
5) X. Wang *et al.*, "A weakly-supervised framework for COVID-19 classification and lesion localization from chest CT," *IEEE Trans. Med. Imag.*, early access, May 20, 2020, doi: 10.1109/TMI.2020.2995965.
6) D.-P. Fan *et al.*, "Inf-net: Automatic COVID-19 lung infection segmentation from CT images," *IEEE Trans. Med. Imag.*, early access, May 22, 2020, doi: 10.1109/TMI.2020.2996645.
7) L. Zhou *et al.*, "A rapid, accurate and machine-agnostic segmentation and quantification method for CT-based COVID-19 diagnosis," *IEEE Trans. Med. Imag.*, early access, Jun. 11, 2020, doi: 10.1109/TMI.2020.3001810.
8) G. Wang *et al.*, "A noise-robust framework for automatic segmentation of COVID-19 pneumonia lesions from CT images," *IEEE Trans. Med. Imag.*, early access, Jun. 5, 2020, doi: 10.1109/TMI.2020.3000314.
9) W. Xie, C. Jacobs, J.-P. Charbonnier, and B. van Ginneken, "Relational modeling for robust and efficient pulmonary lobe segmentation in CT scans," *IEEE Trans. Med. Imag.*, early access, May 15, 2020, doi: 10.1109/TMI.2020.2995108.
10) S. Roy *et al.*, "Deep learning for classification and localization of COVID-19 markers in point-of-care lung ultrasound," *IEEE Trans. Med. Imag.*, early access, May 14, 2020, doi: 10.1109/TMI.2020.2994459.
11) Y. Oh, S. Park, and J. C. Ye, "Deep learning COVID-19 features on CXR using limited training data sets," *IEEE Trans. Med. Imag.*, early access, May 8, 2020, doi: 10.1109/TMI.2020.2993291.
12) S. Karanam, R. Li, F. Yang, W. Hu, T. Chen, and Z. Wu, "Towards contactless patient positioning," *IEEE Trans. Med. Imag.*, early access, May 6, 2020, doi: 10.1109/TMI.2020.2991954.

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