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Lung Infection Segmentation of COVID-19 in CT Images With Deep Convolutional Neural Network

Mr. Jijo G¹, Mrs. Sukanya S T²

¹Student, Department of MCA, Narayanaguru College of Engineering, Anna University.

²Assistant. Professor, Department of MCA, Narayanaguru College of Engineering, Anna University.

ABSTRACT

In this paper, try to establish a new deep convolutional neural network tailored for segmenting the chest CT images with COVID-19 infections as well as the entire lung from chest CT images, referred to as COVID-SegNet. The proposed method can be hugely beneficial for the early screening of patients with COVID-19. Inspired by the observation in annotation processing, the boundaries of COVID-19 infection regions are highlighted by adjusting the window breadth and window locations, extend Squeeze and excitation (SE) unit, named Feature Variation (FV) block, for handling the confusing boundaries. The main idea of the FV block is to implicitly enhance the contrast and adjust the intensity in the feature level automatically and adaptively for different images. Based on the captured features of previous layers, the FV block employs channel attention to obtain the global parameter to generate new features. In addition to the channel attention, the FV block uses spatial attention to guide the feature extraction from inputs in the encoder. Aggregating these features can effectively enhance the capability of feature representation for the segmentation of COVID-19. Furthermore, we propose a Progressive Atrous Spatial Pyramid Pooling (PASPP) to handle the challenging shape variations of COVID-19 infection areas. PASPP consists of a base convolution module followed by a cascade of atrous convolutional layers, which uses multistage parallel fusion branches to obtain the final features. Each atrous convolutional layer in PASPP only uses atrous filters with a reasonable dilation rate to cover different receptive fields. And by the progressively aggregated information from atrous convolutional layers, the information from multiple scales is effectively fused, which further promotes the performance of COVID-19 pneumonia segmentation. The proposed method achieves state-of-the-art performance. Dice similarity coefficients are 0.987 and 0.726 for lung and COVID-19 segmentation, respectively. Here, conducted experiments on the data collected in China and Germany and show that the proposed deep CNN can produce impressive performance effectively. The proposed network enhances the segmentation ability of the COVID-19 infection, makes the connection with other techniques and contributes to the development of remedying COVID-19 infection.



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Keywords: Neural Network, Machine Learning, COVID-19, Convolutional Layer, Segmentation.

1 Introduction

World Health Organization (WHO) formally announced the outburst of a virus COVID-19, the infection affected through Severe Acute Respiratory Syndrome (SARS) CoV-2 in March 2020. COVID-19 is extremely contagious and may become a lethal syndrome of Acute Respiratory Distress (ARDS). Initial exposure and analysis are the key elements in controlling the spread of virus disease. The most common screening process to detect and test the virus is Reverse-Transcription Polymerase Chain Reaction. Though it is a strenuous operation and several analyses have stated its less sensitivity in the primary stage. CT screening dataset to diagnose the latest COVID-19 corona, SARS-COV-2, Virus ailment, which first appeared in Wuhan, China in December 2019 and has caused 64,384 deaths to date, nearly one million confirmed cases worldwide, as of 5 April 2019, with many more to be tested. Reverse transcription polymerase chain reaction (RT-PCR) is one of the standard diagnostic methods to detect nucleotides from specimens obtained by oropharyngeal swab, nasopharyngeal swab, Broncho alveolar lavage, or tracheal aspirate. However, recent reports have indicated that the sensitivity of RT-PCR might not be high enough for detecting COVID-19 which can possibly be attributed to quality, stability and insufficient viral material in specimens. On the other hand, since chest Computed tomography (CT) images captured from COVID-19 patients frequently show bilateral patchy shadows or ground glass opacity in the lung, CT has become a vital complementary tool for detecting the lung associated with COVID-19. Comparing to RT-PCR test, chest CT is relatively easy to operate and has a high sensitivity for screening COVID-19 infection. A CT scan produces accurate organ images, muscles, fleshy tissue, and lifeblood vessels. Doctors can discern interior structures, shape, scale, texture, and density through CT images. Thus, CT scans have far further accurate image conditions of the patients than standard X-Rays. It is necessary to use this basic information to decide when a medical condition occurs as well as the degree and specific position of the issue. Aimed at these purposes, various DL methodologies for COVID-19 screening have recently suggested in CT scans.



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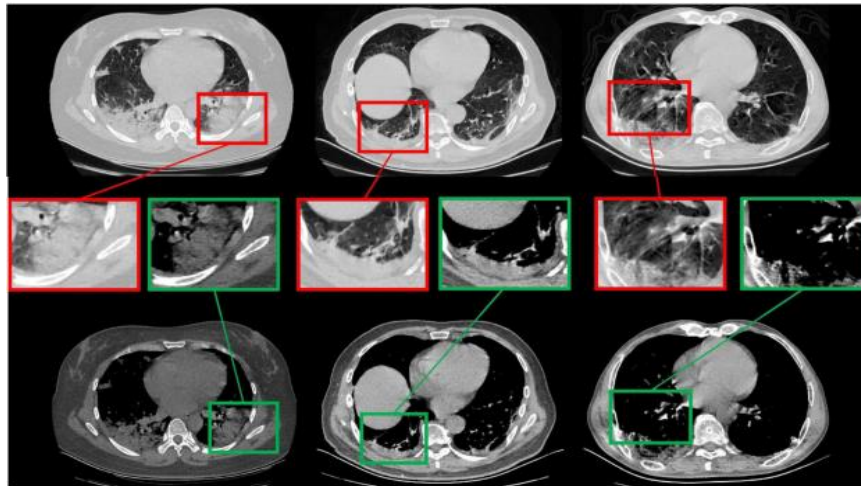


Figure 1: Chest CT images of three patients with laboratory proven COVID19 pneumonia

2 Recent Works

The majority of COVID-19 cases (77%) have been found in China (3, 4). Patients infected with COVID-19 typically present with fever, cough, dyspnoea, and muscle aches while imaging frequently reveals bilateral pneumonia. The standard diagnostic method used is real-time reverse-transcription polymerase chain reaction (RT-PCR), which helps detect viral nucleotides from specimens obtained with oropharyngeal swab, nasopharyngeal swab, Broncho alveolar lavage, or tracheal aspirate. However, recent reports have revealed that RT-PCR has a sensitivity as low as 60%–71% for helping detect COVID-19.

2.1 Correlation of Chest CT and RT-PCR Testing for Coronavirus Disease 2019 (COVID-19) in China: A Report of 1014 Cases, Tao Ai, 2020

Since December 2019, a number of cases of “unknown viral pneumonia” related to a local seafood wholesale market were reported in Wuhan City, Hubei Province, China. A novel corona virus (severe acute respiratory syndrome corona virus 2, or SARS-CoV-2) was suspected to be the cause, with *Phinolophus* bat as the alleged origin. In just 2 months, the virus has spread from Wuhan to the rest of China and another 33 countries. According to the latest guideline of Diagnosis and Treatment of Pneumonitis Caused by 2019-nCoV (trial sixth version) published by the Chinese government, the diagnosis of COVID-19 must be confirmed by means of reverse-transcription polymerase chain reaction (RT-PCR) or gene sequencing for respiratory or blood specimens, as the key indicator for hospitalization. However, with limitations of sample collection and transportation and limitations in kit performance, the total positive rate of RT-PCR for throat swab samples was reported to be approximately 30%–60% at initial presentation. In the current emergency, the low sensitivity



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of RT-PCR implies that many patients with COVID-19 may not be identified and may not receive appropriate treatment in time; such patients constitute a risk for infecting a larger population given the highly contagious nature of the virus. Chest CT, as a routine imaging tool for pneumonia diagnosis, is relatively easy to perform and can produce fast diagnosis. To better understand the diagnostic value of chest CT compared with RT-PCR testing, we report the results of chest CT in comparison to the initial and serial RT-PCR results in 1014 patients suspected of having COVID-19.

2.2 An Attention-guided Deep Neural Network with Multi-Scale Feature Fusion for Liver Vessel Segmentation, Qingsen Yan, 2015

Liver vessel segmentation is fast becoming a key instrument in the diagnosis and surgical planning of liver diseases. In clinical practice, liver vessels are normally manually annotated by clinicians on each slice of CT images, which is extremely laborious. Several deep learning methods exist for liver vessel segmentation, however, promoting the performance of segmentation remains a major challenge due to the large variations and complex structure of liver vessels. The proposed AGC module focuses on capturing rich complemented information to obtain more details. In addition, we introduce an innovative multi-scale fusion block by constructing hierarchical residual-like connections within one single residual block, which is of great importance for effectively linking the local blood vessel fragments together. Furthermore, we construct a new dataset containing 40 thin thickness cases (0.625mm) which consist of CT volumes and annotated vessels. To evaluate the effectiveness of the method with minor vessels, we also propose an automatic stratification method to split major and minor liver vessels. Additionally, we conduct a series of ablation studies that comprehensively support the superiority of the underlying concepts. In this work, we propose a novel deep neural network for liver vessel segmentation, named LVSNet, which employs special designs to obtain the detailed structure of the liver vessel. It has been proven the high-level features typically capture global context-aware information (i.e. vessel shapes), and the low-level features comprise spatial structural details (i.e. Vessel contours), thus the features from different layers of the network are complementary.

2.3 Performance of Radiologists in Differentiating COVID-19 from Non-COVID-19 Viral Pneumonia at Chest CT, Harrison X. Bai, 2020

Since the initial outbreak of coronavirus disease 2019 (COVID-19) in Wuhan, China, in late December 2019, 105586 cases have been confirmed, and 3584 deaths have been reported across 60 countries as of March 9, 2020. The majority of COVID-19 cases (77%) have been found in China (3, 4). False-negative findings hinder quarantine efforts, necessitate repeat testing, and have the potential to overload the current supply of testing kits and related infrastructure. By contrast, chest CT has demonstrated about 56%–98% sensitivity in in the



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detection of COVID-19 at initial presentation and can be helpful in rectifying false-negative findings obtained with RT-PCR during the early stages of disease development. Chest CT images in patients with COVID-19 reveal areas of consolidation and ground-glass opacity with bilateral peripheral involvement in multiple lobes progressing to “crazy paving” patterns and consolidation. CT signs gradually improve beginning approximately 14 days after symptom onset. Despite its high sensitivity in diagnosing COVID-19 in a screening population, chest CT had low specificity (25%) in a recent report of 1014 patients with COVID-19. Previous studies have not directly compared chest CT patterns of COVID-19 with those of viral pneumonia at chest CT.

2.4 Breathing Aid Devices to Support Novel Coronavirus (COVID-19) Infected Patients, Md. Milon Islam, 2020

This pandemic is imposing specific pressures on the medical system almost the whole globe. The respiration problem is the main complication that a COVID-19 infected patient faced generally. The infected, death and recovered cases for this disease are 18,514,884, 699,027, and 11,731,138, respectively, around the world. Due to this pandemic, almost all the sectors including the healthcare system are facing a serious crisis of infrastructure both in developed and developing countries. The major symptoms for COVID-19 are fever, tiredness, breathing difficulties, and dry cough. Oxygen therapy devices are an appropriate solution for the COVID-19 patients, generally available in hospitals as well as ambulance. Ventilators both invasive and non-invasive are mostly used devices for breathing assistance in the hospital environment. The recent deployment of CPAP devices has emerged a direction for the patients having breathing problem.

3. Proposed Work

The proposed system includes the feature variation block and progressive atrous spatial pyramid pooling block. Introduce the architectures of FV block by considering a material fact, the boundaries of COVID-19 infection regions are highlighted by adjusting the window breadth and window locations. As shown in Figure 2, the proposed FV block includes three branches, i.e., contrast enhancement branch, position sensitive branch, and identity branch. Specifically, the contrast enhancement branch learns a global parameter via a channel attention unit to highlight useful boundary information. The position sensitive branch obtains a weight map by spatial attention unit to focus on the COVID-19 regions. Finally, the FV block preserves more useful information by fusing these refined features.



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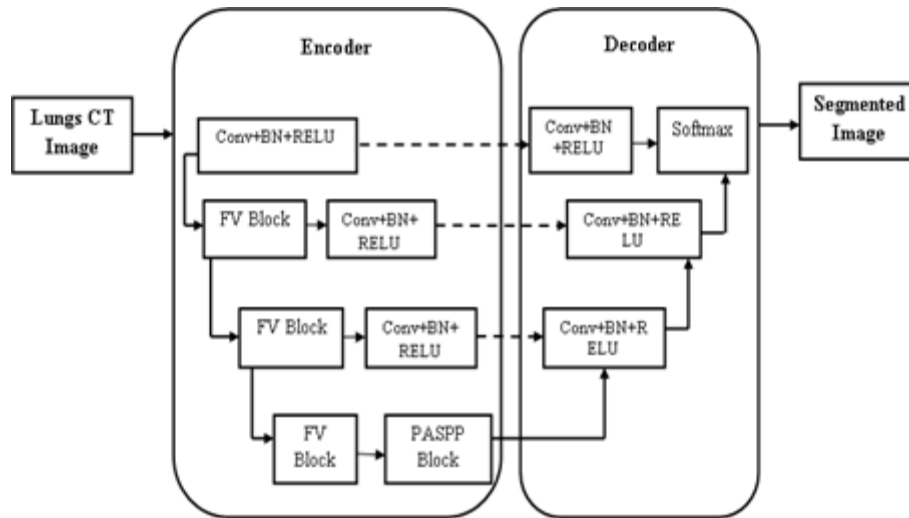


Figure 2: Architecture Diagram

3.1 Feature Variation

As mentioned before, the boundaries of COVID-19 infection regions are highlighted by adjusting the window breadth and window locations, the designed FV block, which includes contrast enhancement branch, position sensitive branch and identity branch, tries to enhance the contrast of features and highlight the useful regions. Let Fv_{in} denotes the input feature, the features after $1 \times 1 \times 1$ represent Fv_1 . The output feature Fv_{out} is given as

$$Fv_{out} = Fv_{in} + Cov_3(Conca(C(Fv_1), P(Fv_1), Fv_1)) \quad (1)$$

Where $Cov_3(.)$ denotes the $1 \times 1 \times 1$ convolutional layer, $Conca(.)$ is the concatenation operation, $C(.)$ represents the contrast enhancement branch, $P(.)$ is the position sensitive branch. The form of residual learning in Eq implies that the information from the early blocks can quickly flow to the later blocks, and the gradient can be quickly back-propagated to the early blocks from the later blocks. The details of each sub-module are as follows.

- A) Contrast Enhancement Branch
- B) Position Sensitive Branch

3.2 Progressive Atrous Spatial Pyramid Pooling

In this subsection, start with a preliminary knowledge of atrous spatial pyramid pooling, then introduce the proposed PASPP block.

- A) Atrous Spatial Pyramid Pooling
- B) The PASPP Block



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4 Result and Discussion

The screening performance of the proposed method is conducted by the Dice similarity coefficient, sensitivity, and precision. The Dice similarity coefficient (Dice) represents a similarity metric between the ground truth, and the prediction score maps

$$Dic(A, B) = \frac{2|A \cap B|}{|A| + |B|},$$

Where A is the segmented infection region, B denotes the corresponding reference region, $|A \cap B|$ represents the number of pixels common to both images. Sensitivity denotes the number of correctly identified positives with respect to the number of positives. Precision is the fraction of positive instances among the retrieved instances.



Figure 3(a): Input Image

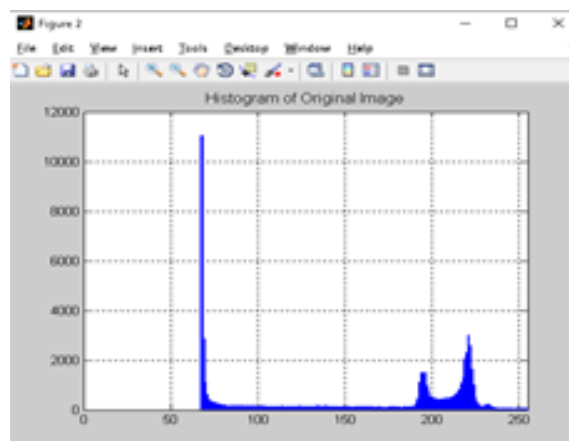


Figure 3(b): Histogram of Input Image



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Figure 3(c): *Contrast Enhancement*

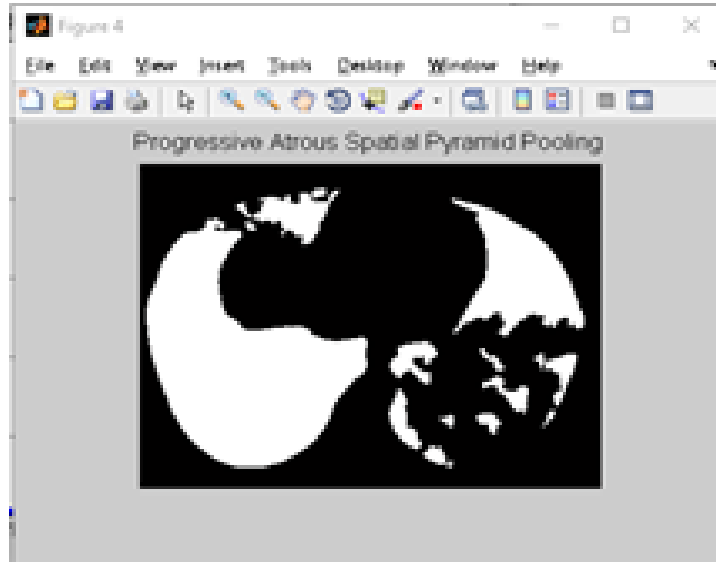


Figure 3(d): *Progressive Atrous Spatial Pyramid Pooling*



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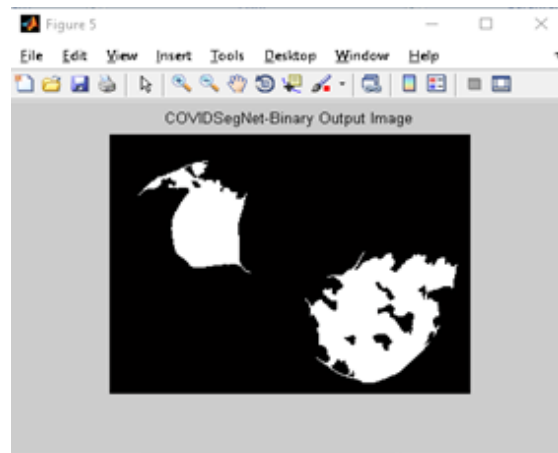


Figure 3(e): COVID SegNet-Binary Output Image

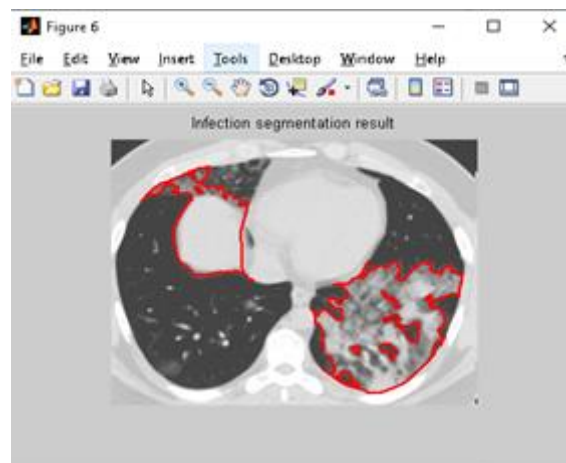


Figure 3(f): Infection Segmentation Result

5 Conclusion

In this paper, designed and evaluated a deep learning model, called COVID-SegNet, for segmenting lung and COVID-19 from chest CT images. Inspired by contrast enhancement methods and ASPP, the proposed network includes feature variation and progressive ASPP blocks, which are beneficial to highlight the boundary and position of COVID-19 infections. These results demonstrate that the convolutional network-based deep learning technology has the ability to segment COVID-19 from CT images. We were able to collect a large number of CT images from 5 hospitals, which included 861 patients with confirmed COVID-19. More



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importantly, we manually annotated these data by senior annotators. These contributions prove the prospect of improving diagnosis and treatment for COVID-19.

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