WSO-CAPS: Diagnosis of Lung Infection from Low and Ultra-Low Dose CT Scans Using Capsule Networks and Window Setting Optimization

Shahin Heidarian[1], Parnian Afshar[2], Nastaran Enshaei[2], Farnoosh Naderkhani[2], Moezedin Javad Rafiee, MD[3], Anastasia Oikonomou, MD[4], Faranak Babaki Fard, MD[5], Akbar Shafiee, MD[6], Konstantinos N. Plataniotis[7], and Arash Mohammadi[2]

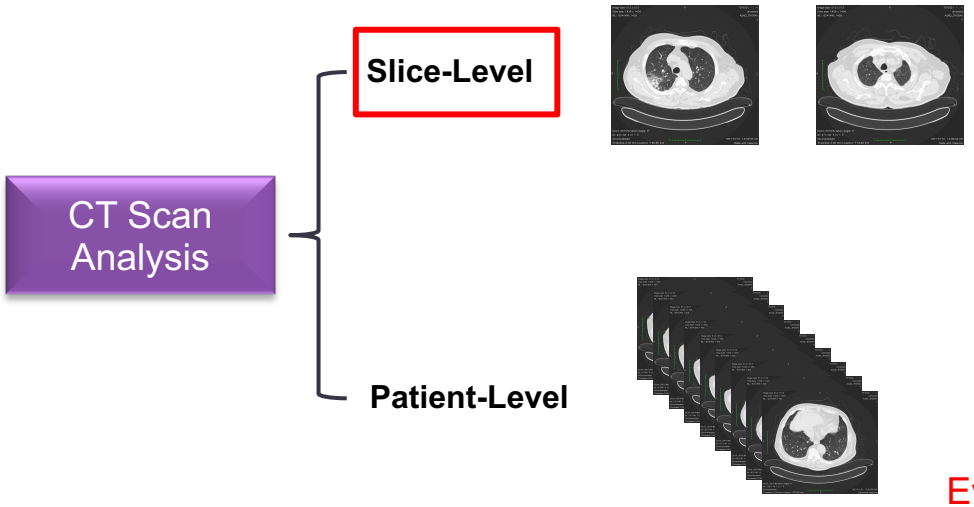
1. Department of Electrical and Computer Engineering, Concordia University, Montreal, Canada
2. Concordia Institute for Information Systems Engineering, Concordia University, Montreal, Canada
3. Department of Medicine and Diagnostic Radiology, McGill University, Montreal, Canada
4. Department of Medical Imaging, Sunnybrook Health Sciences Centre, Toronto, Canada
5. Biomedical Sciences Department, Faculty of Medicine, University of Montreal, Montreal, Canada
6. Department of Cardiovascular Research, Tehran Heart Center, Cardiovascular Diseases Research Institute, Tehran University of Medical Sciences, Tehran, Iran
7. Department of Electrical and Computer Engineering, University of Toronto, Toronto, Canada

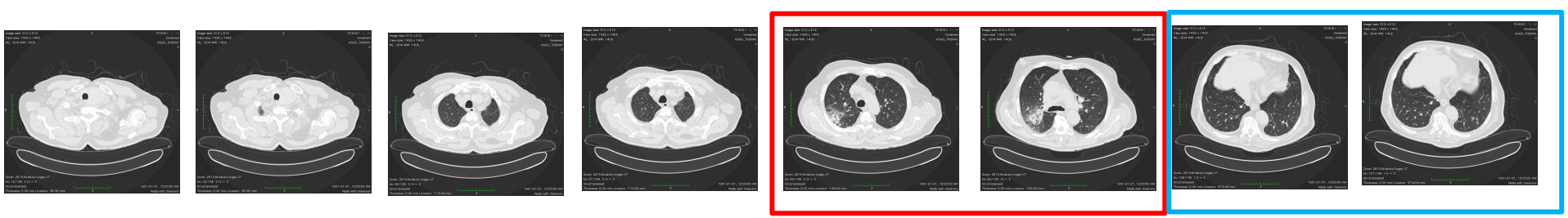
Outline

Introduction

Goal: Predict the Existence of Infection in Lung CT scans

CT scans are generated by cross-sectional images obtained by sending X-ray beam into the body and monitoring the signal passed through the body.
CT scans provide a 3D representation of the body constructed by a sequence of 2D images (slices).





Introduction

CT Scan Characteristics

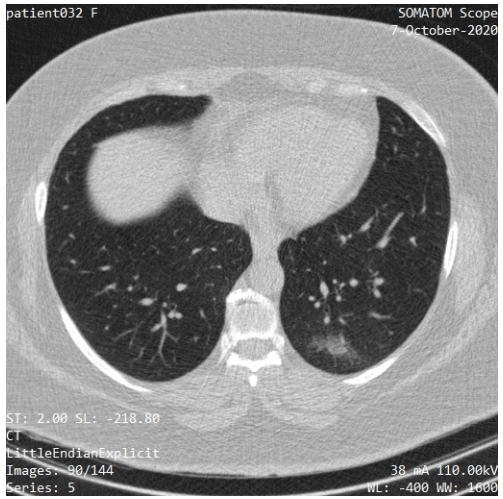
Expose patients to harmful radiations with devastating effects on the body.

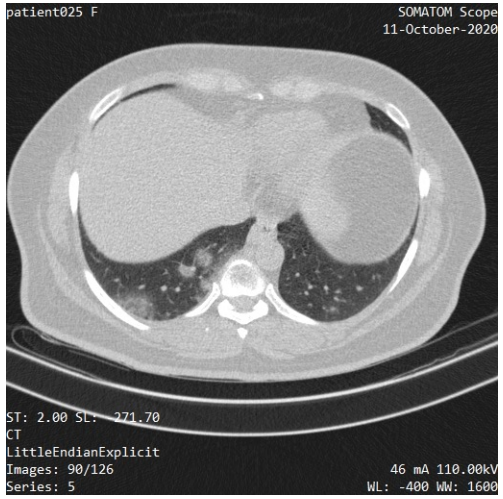
Standard Dose CT Scans → Low Dose and Ultra-Low Dose CT Scans (LDCT and ULDCT)

Decreasing the X-Ray tube current → High Level of Noise

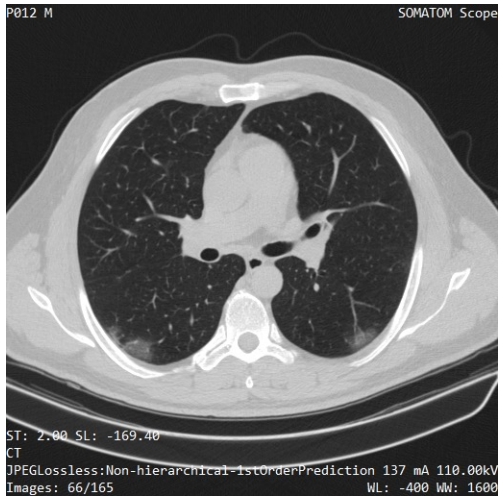
Introduction

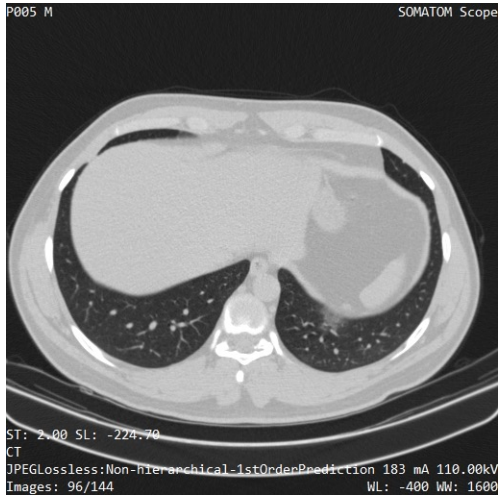
Low Dose





Standard Dose





Introduction

Radiologists' Approach

CT scans are mainly represented in the Hounsfield Units(HU) in which pixel intensities are commonly distributed from HU air (-1000) to > 4000.

Some manifestations are only visible in a specific window depending on their tissue density.

Adjust Window Settings (WL, WW)

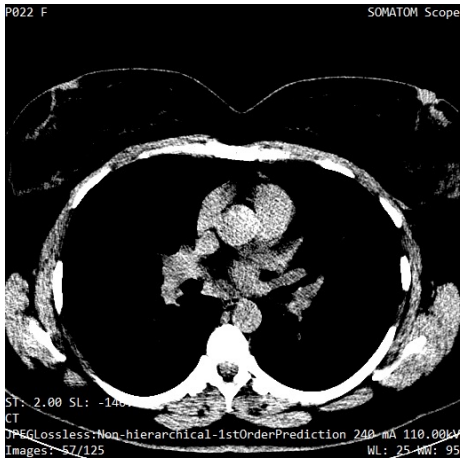
→

Narrow down the displayed components

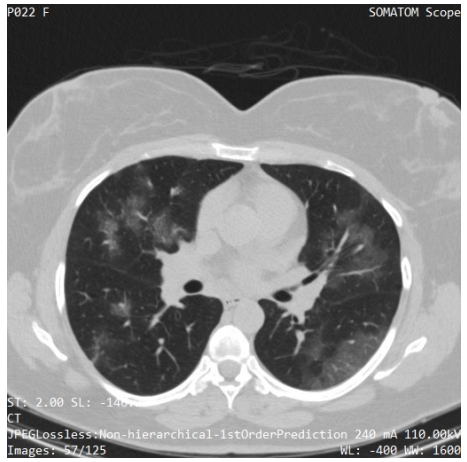
Adjust the image contrast

Introduction

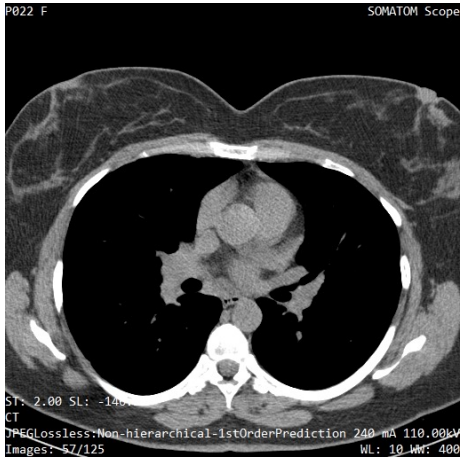
(WL= 25 , WW = 95)



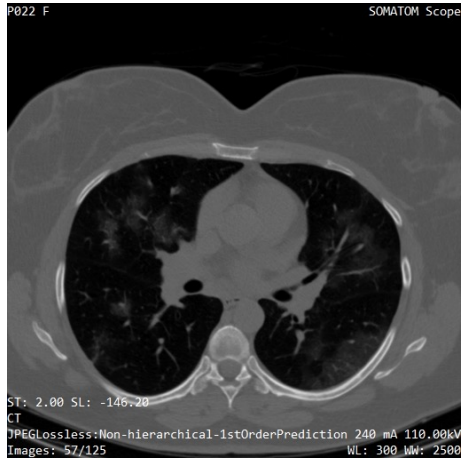
(WL= -400 , WW = 1600)



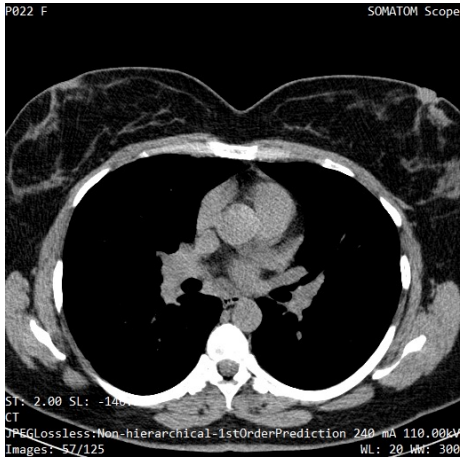
(WL= 10 , WW = 400)



(WL= 300 , WW = 2500)



(WL= 20 , WW = 300)



Contributions

1. Embedded a Window Setting Optimization module into the Binary Classifier.
2. Detected 3 best window settings for Lung CT scans.
3. Modified an existing CapsNet classifier to detect Slices with and without the evidence of infection (caused by different diseases).
4. Enhanced the overall performance of the binary classification.

Dataset

1. Low and Ultra-Low Dose CT scans

100 COVID-19 + 60 Normal cases

Volumetric Scan in the axial view

Reconstructed by Filtered Back Projection

LDCT: 20 mAs
ULDCT: 15 mAs

7,703 slices with the evidence of infection

15,464 slices without the evidence of infection

2. Simulated Low Dose CT scans

60 CAP cases

Simulated based on standard dose scans

Using CycleGAN

3,359 slices with the evidence of infection

5,768 slices without the evidence of infection

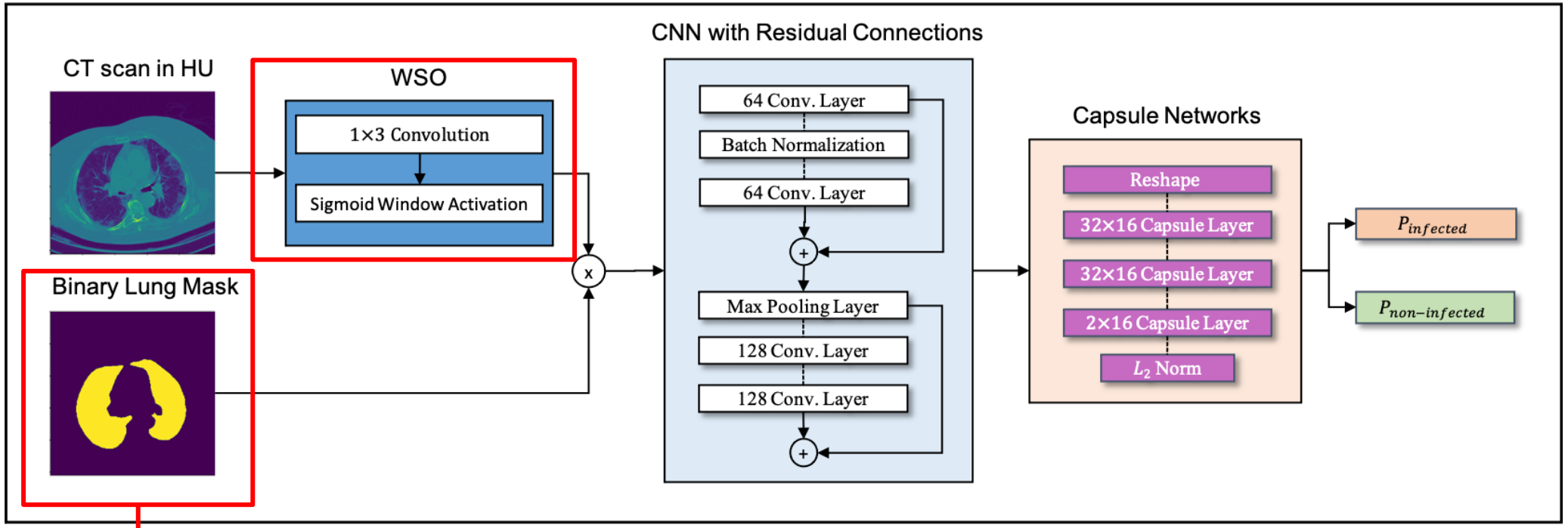
3. Standard Dose CT Scans (COVID-CT-MD)

54 COVID-19 + 60 CAP + 60 Normal cases

7,138 slices without the evidence of infection

21,442 slices with the evidence of infection

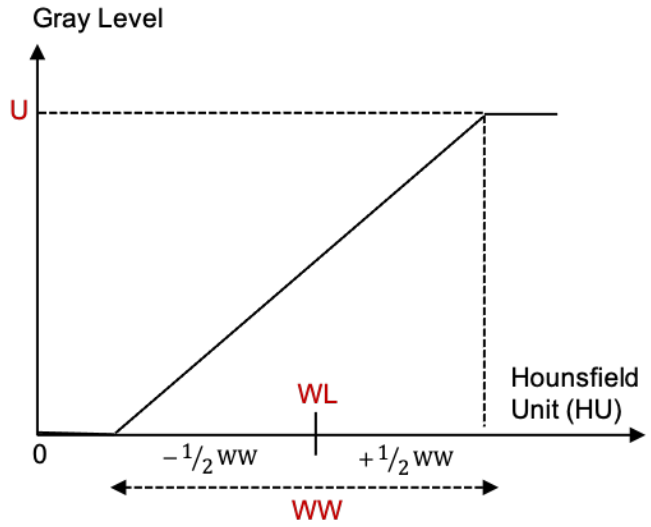
WSO-CAPS Framework



- U-net-based model (R231CovidWeb)
- Pre-trained on different diseases and fine-tuned on the COVID-19 CT scans

WSO-CAPS Framework: Windowing Functions

Linear

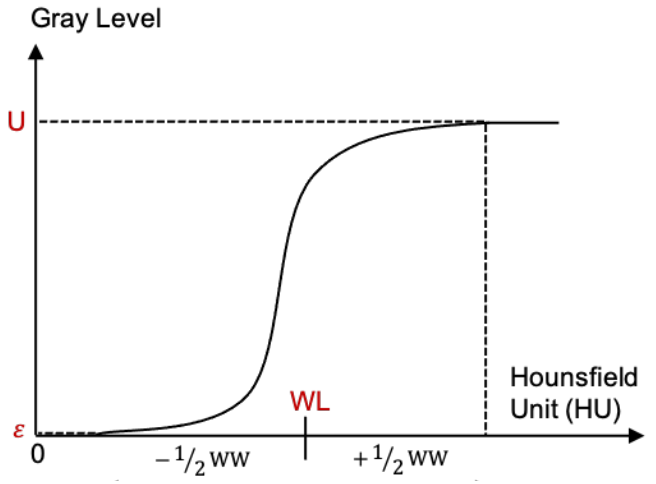


$$F_{lin}(x) = min(max(Wx + b, U), 0),$$

$$W = \frac{U}{WW}$$

$$b = -\frac{U}{WW}(WL - \frac{WW}{2})$$

Sigmoid



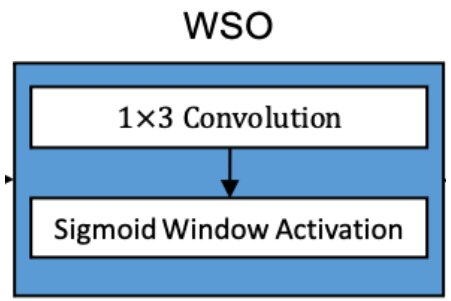
$$F_{sig}(x) = \frac{U}{1 + \exp -(Wx + b)},$$

$$W = \frac{2}{WW} log(\frac{U}{\epsilon} - 1)$$

$$b = \frac{-2WL}{WW} log(\frac{U}{\epsilon} - 1)$$

Loss Function: $$loss = \frac{N^+}{N^+ + N^-} \times loss^- + \frac{N^-}{N^+ + N^-} \times loss^+$$

WSO Implementation



$$F_{lin}(x) = min(max(Wx + b, U), 0),$$

$$F_{sig}(x) = \frac{U}{1 + \exp -(Wx + b)},$$

- Convolution layer with 1,1 filter size and a stride of 1,
- → followed by an Activation layer which is either a rectified linear unit (ReLU), or sigmoid function multiplied by U.

Results

Initial Windowing Parameters: WL = -500 ; WW = 1400

Performance	CapsNet	CapsNet (+Residual Connection)	WSO-CAPS (ReLU)	WSO-CAPS (sigmoid)	WSO-CAPS (sigmoid, no lung segmentation)
Accuracy(%)	89.4	89.5	91.4	**91.6**	90.3
Sensitivity(%)	85.5	86.3	**91.7**	89.1	85.7
Specificity(%)	92.2	91.9	91.2	93.5	**93.9**

Performance	WSO-CAPS (3 channels)	WSO-CAPS (3 Branches)	WSO-CAPS (3 Channels - 3 Branches)	ResNet50 (Ref [23])
Accuracy(%)	**92.0**	91.0	91.5	83.1
Sensitivity(%)	**90.3**	88.5	88.4	76.4
Specificity(%)	93.3	92.8	**93.7**	88.0

- Increasing the number of channels and branches didn't show any improvement.

Results

Experiment on Standard Dose Scans:

Performance	WSO-CAPS (Standard Dose Scans)	CapsNet (without WSO)
Accuracy (%)	91.6	90.5
Sensitivity (%)	92.0	89.8
Specificity (%)	91.4	90.7

Results: Optimal Window Settings

WSO-CAPS using 1 channel → (WL: -555.9 , WW: 1032.0)

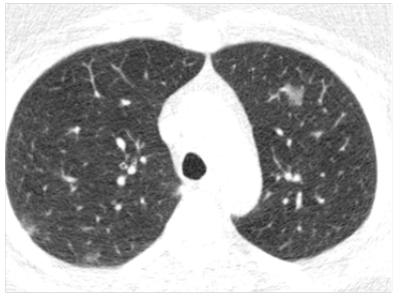
WSO-CAPS using 3 channels →

Window 1: (-592.4 , 1095.7)

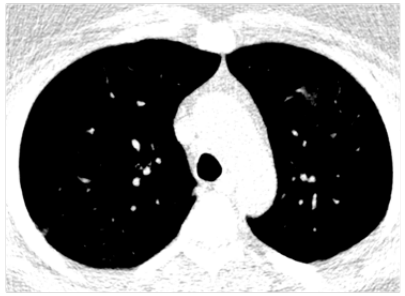
Window 2: (-277.1 , 517.8)

Window 3: (-630.4 , 1165.4)

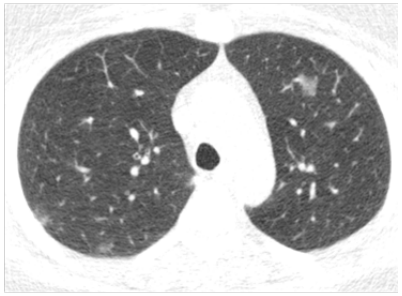
Slice 1 – Window 1



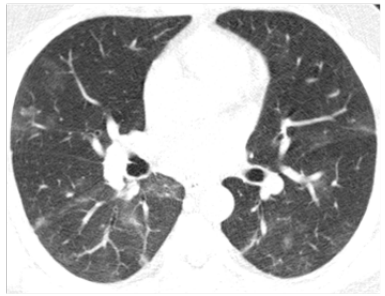
Slice 1 – Window 2



Slice 1 – Window 3

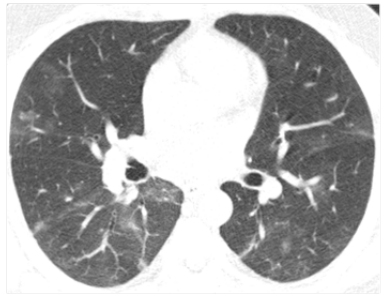


Slice 2 – Window 1



Slice 2 – Window 2

Slice 2 – Window 3



Conclusion

- ✓ Developed a binary classifier to identify slices demonstrating infection from LDCT and ULDCT.
- ✓ Enhanced the classification performance by adding shortcut connections and the WSO module.
- ✓ Detected 3 optimal window settings to identify lung infections.
- ✓ The proposed WSO-CAPS have a high potential to be incorporated in other models related to CT scans to improve their overall performance and limit the process on a small subset of candidate slices or ROIs.

References

1. Afshar, P. *et al.* ”COVID-CT-MD, COVID-19 computed tomography scan dataset applicable in machine learning and deep learning,” *Sci Data* 8, 121 (2021). doi: 10.1038/s41597-021-00900-3

2. Heidarian, S. *et al.* “COVID-FACT: A Fully-Automated Capsule Network-Based Framework for Identification of COVID-19 Cases from Chest CT Scans,” Front. Artif. Intell., 2021. doi: 10.3389/frai.2021.598932

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4. Heidarian, S. *et al*., "Ct-Caps: Feature Extraction-Based Automated Framework for Covid-19 Disease Identification From Chest Ct Scans Using Capsule Networks," *ICASSP 2021 - 2021 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2021, pp. 1040-1044, doi: 10.1109/ICASSP39728.2021.9414214.

Thank you.

Thank You, Please forward your further questions to: s_idari@encs.concordia.ca