Line artefact quantification in lung ultrasound images of COVID-19 patients using a non-convex regularization-based method

O. Karakuş[1] N. Anantrasirichai[1] A. Aguersif[2] S. Silva[2] A. Basarab[3] A. Achim[1]

[1] University of Bristol, UK,
[2] Service de Reanimation, CHU Purpan, Toulouse, France,
[3] IRIT, Universite Paul Sabatier Toulouse, France.

GdR ISIS
Diagnostic et pronostic pour la COVID-19
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University of Bristol
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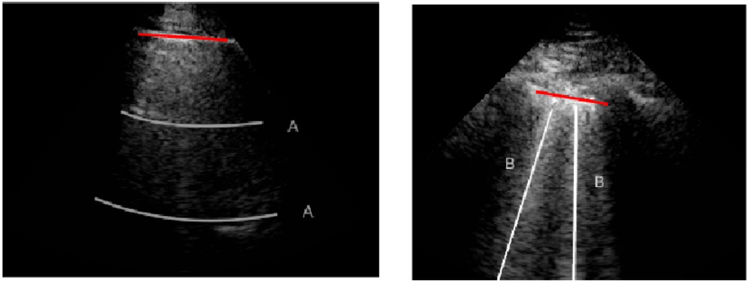
Outline

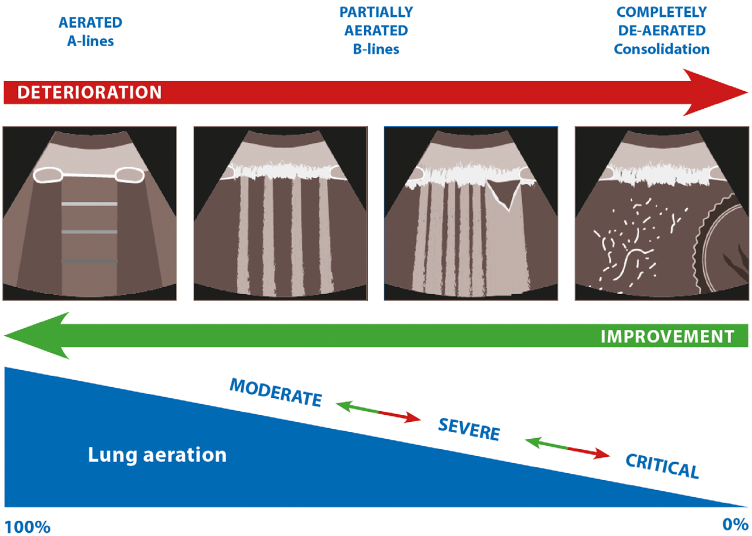
- ✓ Local to the lungs: Pneumonia, COPD, Lung Cancer.
- ✓ Manifesting themselves in the lungs: Kidney Disease, Tuberculosis, COVID-19.
- ✓ Causes death of +100.000 people/year in the UK.
- ✓ Somebody dies due to pulmonary diseases in the UK in every 5 minutes.
- ✓ The 3^{rd} common death reason in the UK.

(FC: nih.gov)

- ✓ Lung ultrasound (LUS) can help in assessing the fluid status of patients in intensive care
- ✓ LUS can be conducted rapidly and repeatably at the bedside, can reduce the need for CT scans (shorter delays, lower irradiation levels and cost)
- ✓ The common feature in all clinical conditions is the presence in LUS of a variety of line artefacts (e.g., pleural, A, B-lines).

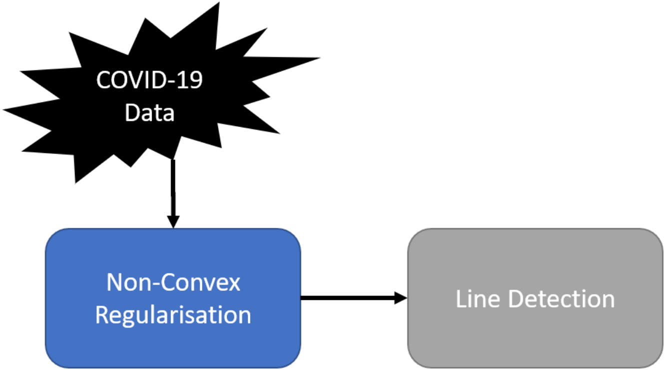


(Karakus et al., IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 2020)



(Smith et al., Anaesthesia, 2020)

The Proposed Algorithm



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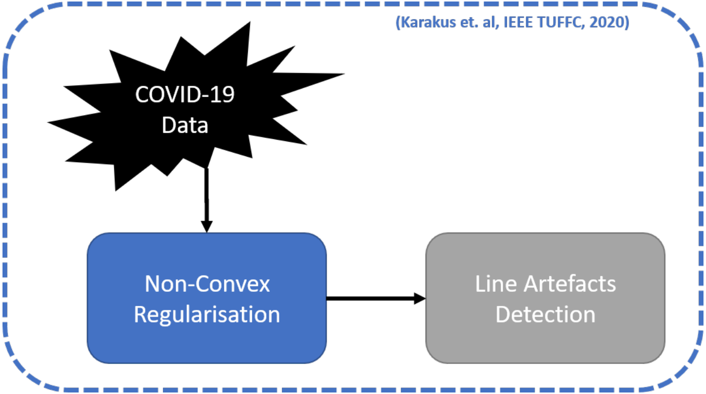

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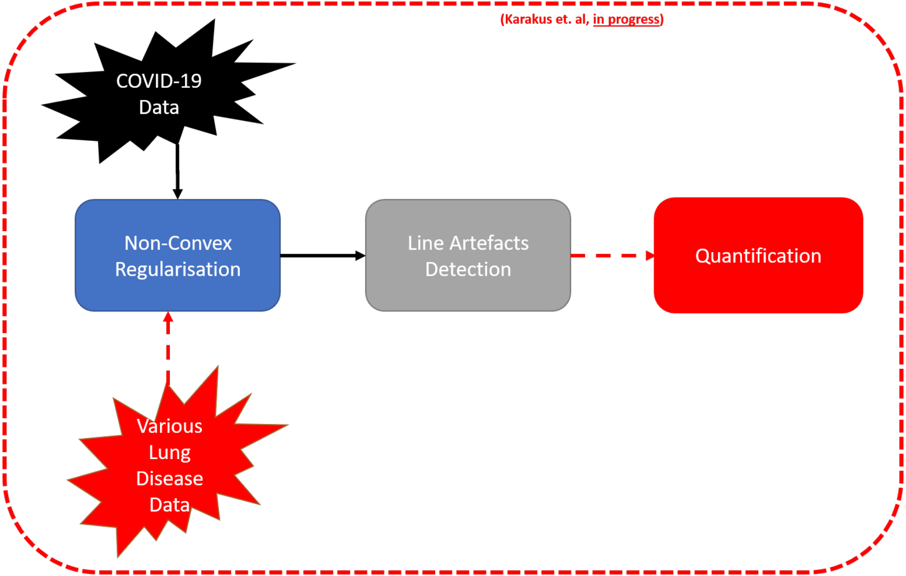
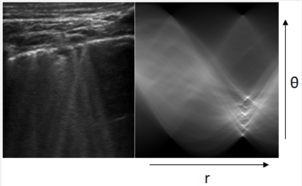


Image Formation

Forward Model

- ✓ Radon transform of a LUS image
- ✓ Speckle noise → False peaks resulting from collinear noisy edge points



- ✓ Solution: Exploiting the fact → a **small number of lines** are to be detected

$$\underbrace{Y}_{\text{LUS image}} = \underbrace{\mathcal{C}X}_{\mathcal{C}\text{: inv. Radon Tr.}} + \underbrace{N}_{\text{Additive Noise}}$$

- ✓ X is sparse Radon information.

Image Formation

Inverse Problem

✓ Recalling the forward imaging model,

$$\hat{X} = \arg\min_{x} \left\{ F(X) = \Psi(Y, \mathcal{C}X) + \psi(X) \right\} \tag{1}$$

✓ Under the assumption of an *i.i.d* Gaussian noise,

$$\Psi(Y, \mathcal{C}X) = \frac{\|Y - \mathcal{C}X\|_2^2}{2\sigma^2} \tag{2}$$

✓ Based on the prior density $p(X)$, the problem of estimating X

$$\hat{X} = \arg\min_{X} \frac{\|Y - \mathcal{C}X\|_2^2}{2\sigma^2} \underbrace{- \log p(X)}_{\text{the penalty function, } \psi(X)} \tag{3}$$

Cauchy Proximal Splitting

Non-convex Cauchy-based Penalty

✓ The Cauchy distribution → Prior Density (to promote sparsity)

$$p(X) \propto \frac{\gamma}{\gamma^2 + X^2} \tag{4}$$

✓ By replacing $p(X)$ with the Cauchy prior, we obtain

$$\hat{x}_{\text{Cauchy}} = \arg\min_x \frac{\|y - \mathcal{A}x\|_2^2}{2\sigma^2} - \log\left(\frac{\gamma}{\gamma^2 + x^2}\right). \tag{5}$$

The Cauchy Proximal Splitting algorithm:

$$u^{(i)} \leftarrow X^{(i)} - \mu \mathcal{C}^T(\mathcal{C}X^{(i)} - Y), \tag{6}$$

$$X^{(i+1)} \leftarrow \text{PROXCAUCHY}(u^{(i)}, \gamma, \mu). \tag{7}$$

Thanks to PROXCAUCHY(·) → Convergence is guaranteed[1].

[1] O. Karakuş *et. al.*, "Convergence Guarantees for Non-Convex Optimisation With Cauchy-Based Penalties," in IEEE Trans. Signal Process., (68), 6159-6170, 2020

Line Artefacts Detection Algorithm

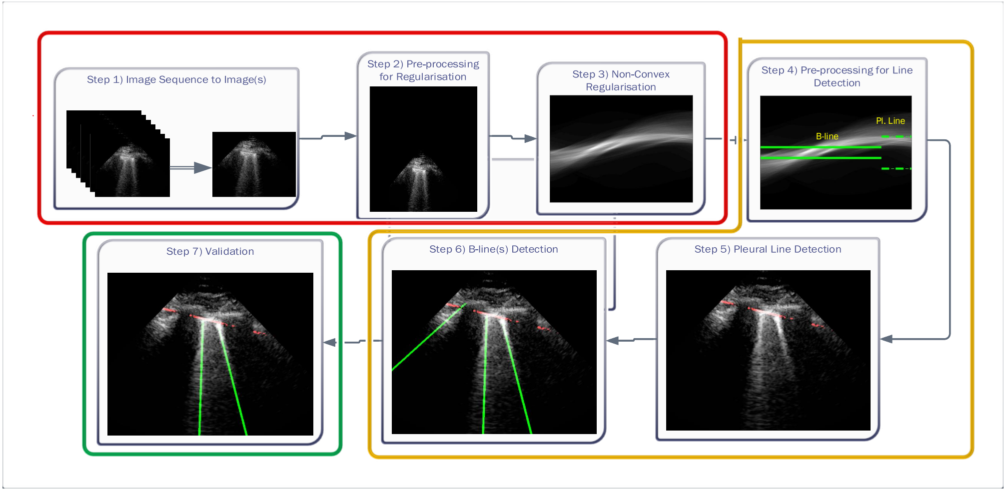


Figure: Schematic view of the proposed line artefact detection algorithm.

Evaluation on COVID-19 Patients*

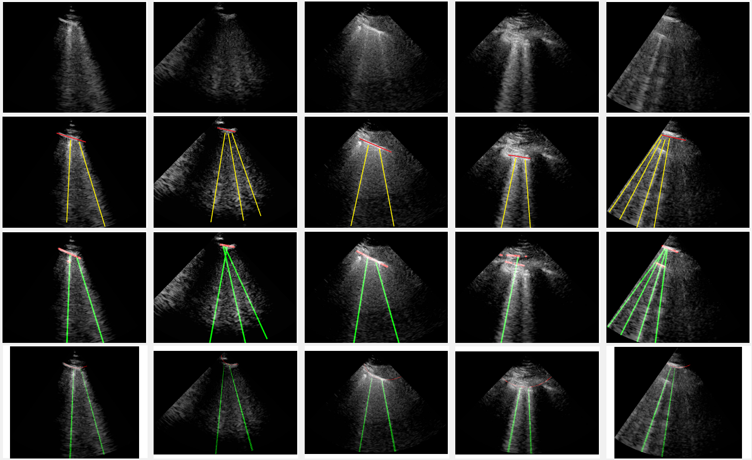
Detection Results

Original images

Ground truth

Proposed method (Karakus *et al*, IEEE TUFFC'20)

[Anantrasirichai *et al*, IEEE TMI'17]



* COVID-19 LUS data and annotations have been provided by Prof. Stein Silva and Dr. Amazigh Aguersif (Service de Réanimation, CHU Purpan, Toulouse, France).

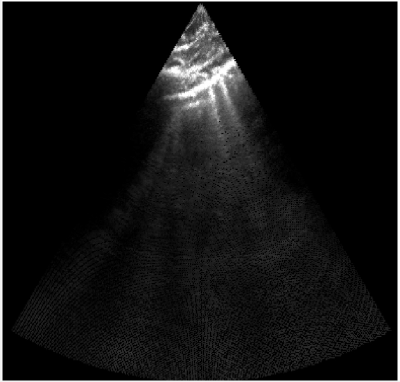
Evaluation on COVID-19 Patients

Performance metrics for B-line quantification

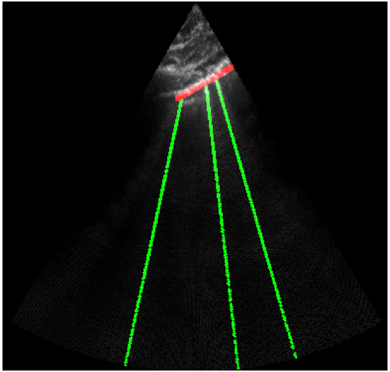
Performance Metric	The Proposed Method	Anantrasirichai et. al.
% Detection Accuracy	87.349%	78.916%
% Missed Detection	5.422%	13.855%
% False Detection	7.229%	7.229%
Specificity	7.692%	14.286%
Recall	94.118%	84.868%
Precision	92.308%	91.489%
F_1 Index	0.932	0.881
F_2 Index	0.938	0.861
$F_{0.5}$ Index	0.927	0.901
LR+	1.020	0.990
Area under curve (AUC)	0.963	0.931
The average number of B-lines (Ground Truth) = 1.520		
Average Detected B-lines	1.550	1.410
NMSE of number of detected B-lines	0.151	0.243

Evaluation on Children's Kidney Disease Patients

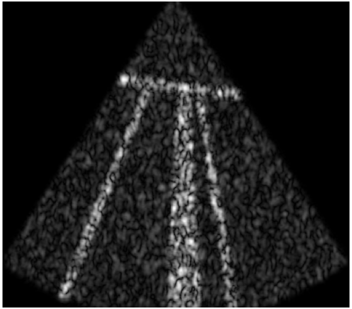
Original Image

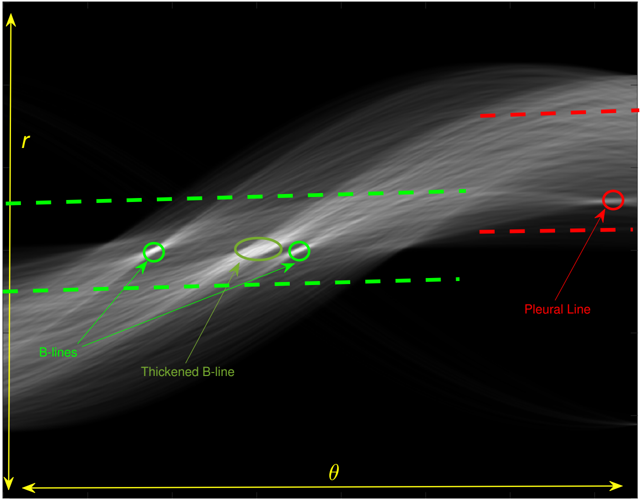


Detection

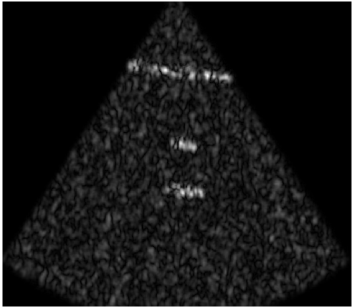


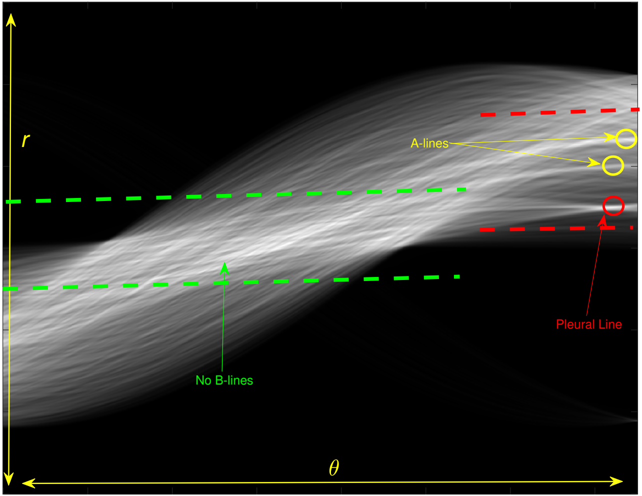
Quantifying Line Artefacts - Case 1: B-lines



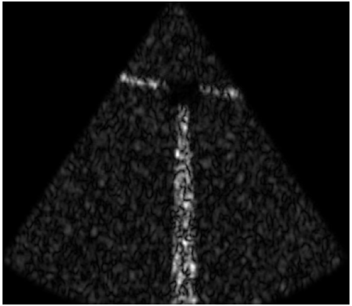


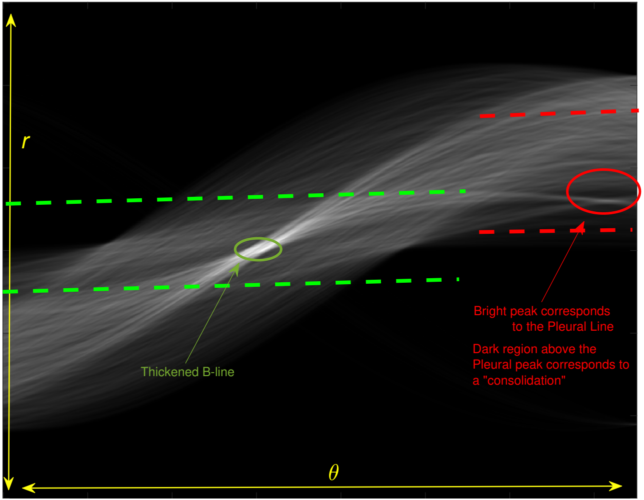
Quantifying Line Artefacts - Case 2: A-lines





Quantifying Line Artefacts - Case 3: Consolidation





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- ✓ **Future work** $\rightarrow$ Fully Bayesian Analysis and Diagnosis Tool for Lung Disease.
- ✓ **Future work** $\rightarrow$ Uncertainty Quantification.

Thank you for your time!

For questions please contact via email:
adrian.basarab@irit.fr

For details of this work please see our TUFFC paper:

[1] O. Karakuş, et .al, "Detection of Line Artifacts in Lung Ultrasound Images of COVID-19 Patients Via Nonconvex Regularization," in IEEE TUFFC, Nov. 2020, doi: 10.1109/TUFFC.2020.3016092.

For Matlab Code:

[2] QuantLUS - CPS v1.0 https://doi.org/10.5523/bris.z47pfkwqivfj2d0qhyq7v3u1i.

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