Ionospheric Echoes Detection in Digital Ionograms Using Convolutional Neural Networks

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INTRODUCTION

An ionogram is a graph that shows the distance that a vertically transmitted wave, of a given frequency, travels before returning to the earth. Along with the echoes of the ionosphere, ionograms usually contain a large amount of noise of different nature, that must be removed in order to extract useful information. In the present work, we propose to use a convolutional neural network model to improve the quality of the information obtained from digital ionograms, compared to that using image processing and machine learning techniques.

DATA SET DESCRIPTION

The data used for the training of the convolutional networks and the evaluation of the baseline models were obtained from the ionosonde database of the distributed observatory LISN (http://lisn.igp.gob.pe).

Fig. 2. Geographic distribution of the LISN ionosondes, nearly aligned with the magnetic flux tube intersecting the magnetic equator at 70 deg West

The LISN database contains more than 1,000,000 ionograms. A set of 50,780 was chosen to train the model, this ionograms were taken between 15:00 and 22:00 hours GMT from years 2016 to 2018. All of them have 512 height and 408 frequency points. From this set, 817 were randomly selected to manually extract ionosphere profiles using a free image manipulation software, which we call manual extraction, these files made up the labeled data set (figure 3).

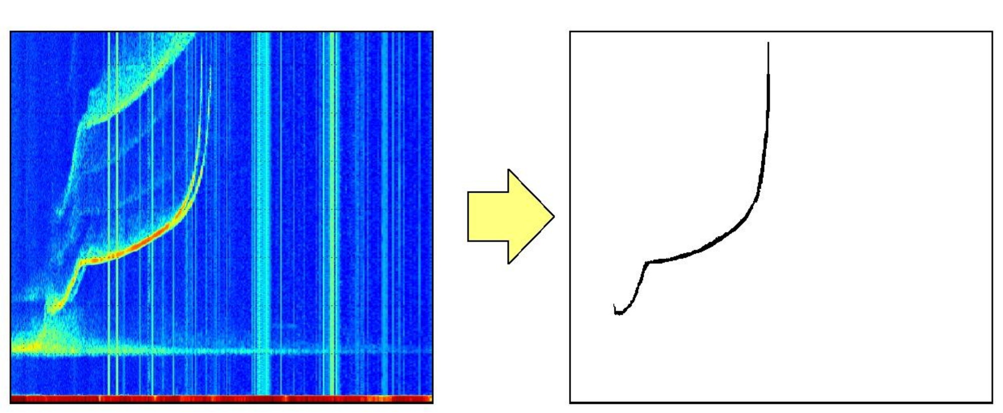


Fig. 3. ionogram before and after being manually converted to a binary image, in which the ionosphere profile has been extracted

PERFORMANCE METRICS

The Intersection over Union (IoU) is used to measure the performance of any object category segmentation method. IoU gives a ratio between the number of pixels common in two images and the total number of pixels in both images.

$$IoU = \frac{common\_area}{total\_area}$$

IMPLEMENTATION AND EVALUATION OF BASELINE MODELS

Image processing and thresholding

ionograms are considered as images, in which the noise must be filtered out to isolate ionospheric echoes. Three types of filters are used in cascade: median filter, the filter defined by the Ker matrix and thresholding.

$$Ker = \begin{pmatrix} 1110111 \\ 1110111 \\ 1110111 \\ 1110111 \\ 1110111 \\ 1110111 \\ 1110111 \end{pmatrix} + \text{Median filter} + \text{Thresholding}$$

As shown in figure 4 it is possible to accurately eliminate the background noise, but neither the interference, nor the calibration signal nor multihop could be eliminated. Average IoU between test set ionograms where the three filters were applied and manually segmented ionograms is 0.163.

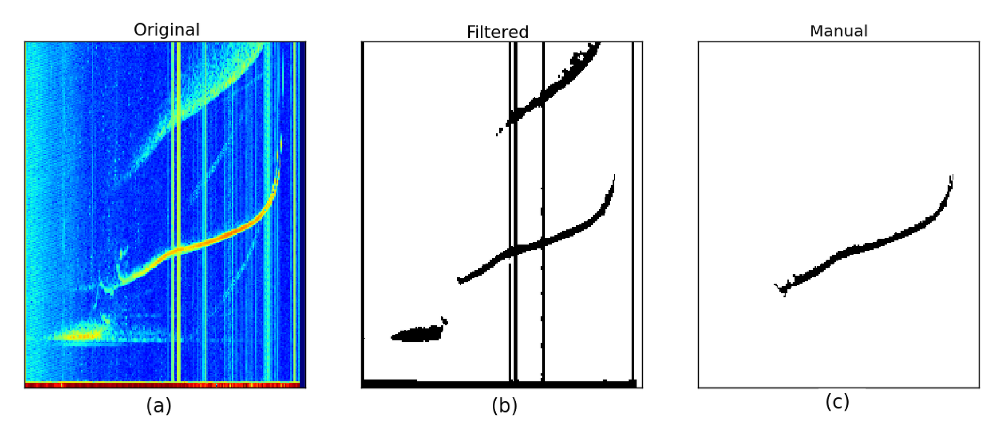


Fig. 4. Comparison between the original ionogram (a), the result of the cascade application of the Ker filter, median filter and thresholding (b) and a manually segmented ionogram (c)

Unsupervised clustering models

The other method is based on the representation of the ionograms in 3-dimensional matrices {x, y, V} where x and y represent spatial coordinates and V the intensity of the point. With this representation 2 unsupervised clustering techniques are applied, K-Means and Mean Shift.

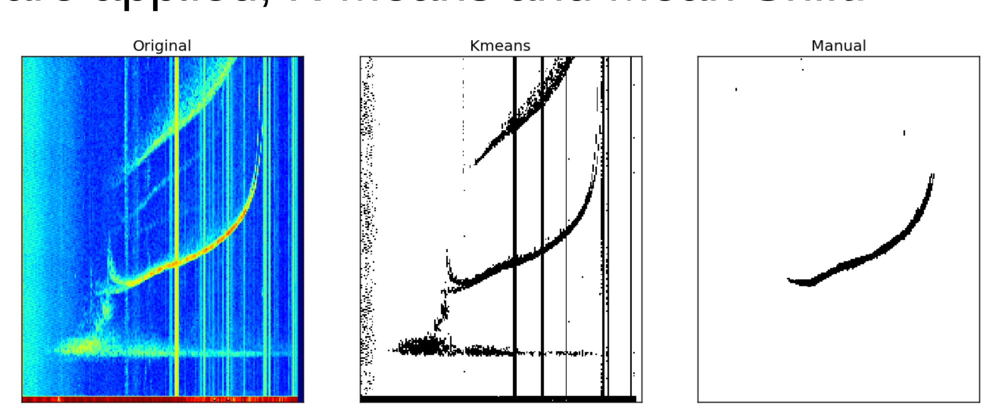


Fig. 5. Kmeans vs Manual segmentation

	IoU
Filtered	0.163
K-Means	0.157
Mean Shift	0.108

IoU of base line models

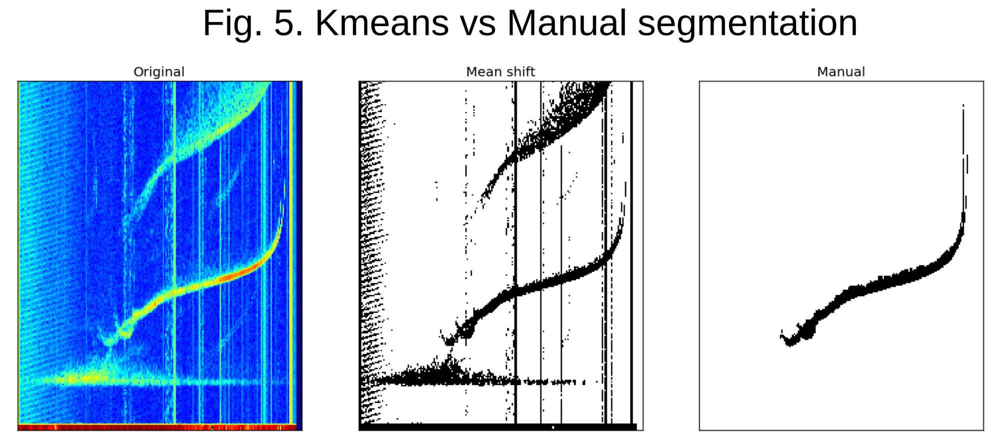


Fig. 6. Mean shift vs Manual segmentation

PROFILE DETECTION USING CONVOLUTIONAL NEURAL NETWORKS

- In the first stage of the learning process the neural network is fed with original ionograms (X), and use as output variables (y) ionograms that have been segmented using the three baseline techniques.
- In the second stage we fine tune the previously trained models. The 3 models are fed again with original ionograms, but the output variables are the manually segmented ionograms.
- As a final stage, the CNN model is trained using only manually segmented ionograms as output data.

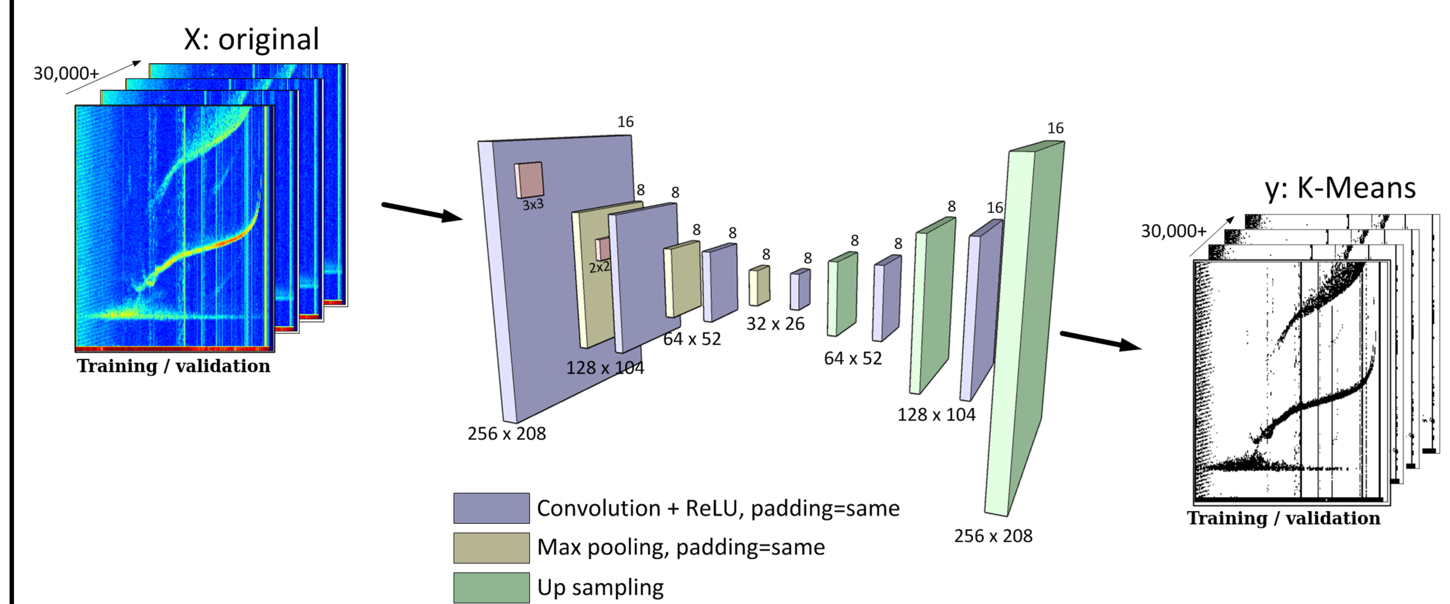
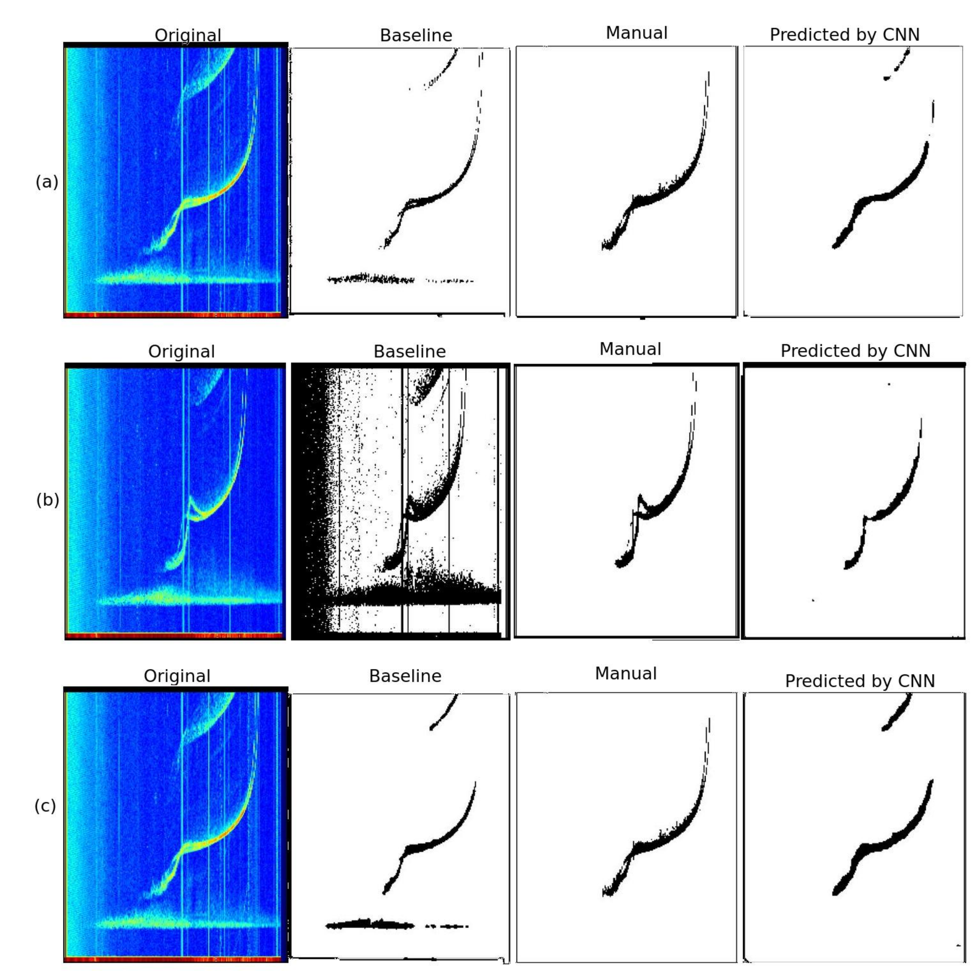


Fig. 7. Neural network model. X = Original ionograms, y = ionograms segmented with K-means



	IoU
Filtered	0.589
K-Means	0.602
Mean Shift	0.593

IoU of CNN models

Fig. 8. Comparison between manual segmentation, segmentation by base line models, and predictions by CNN.

Consluions

- In terms of IoU, segmentation of ionograms when using a neural network trained using labeled data is 5.6 times better than segmentation performed by baseline models.
- The use of large amounts of unlabeled data to generate a pre-trained model slightly improves (<6%) the accuracy of the final model, so we can say that performance of the model is based mainly on the use of a convolutional neural network and not on a pre-training process with unlabeled data.

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