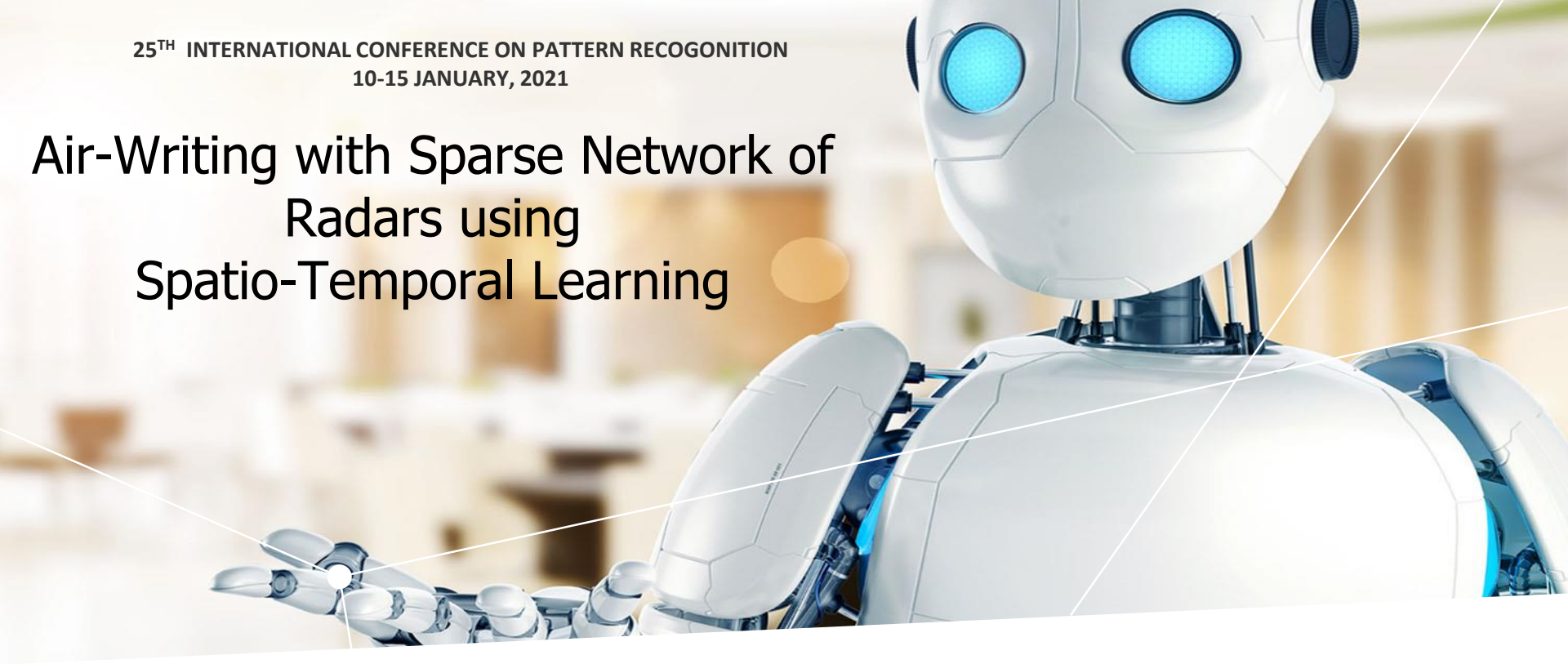
25TH INTERNATIONAL CONFERENCE ON PATTERN RECOGONITION
10-15 JANUARY, 2021

Air-Writing with Sparse Network of Radars using Spatio-Temporal Learning



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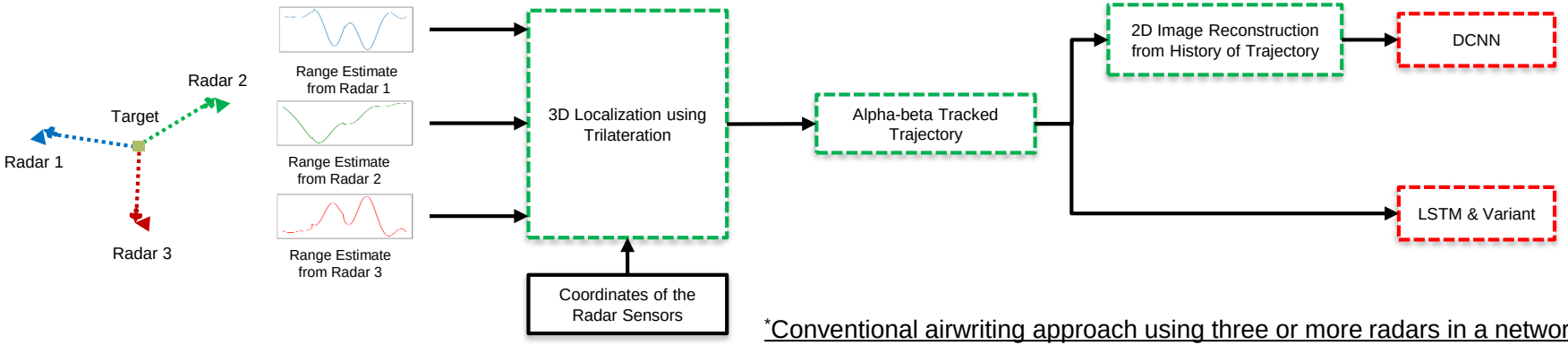
Problem Statement/ Motivation



*Conventional airwriting approach using three or more radars in a network

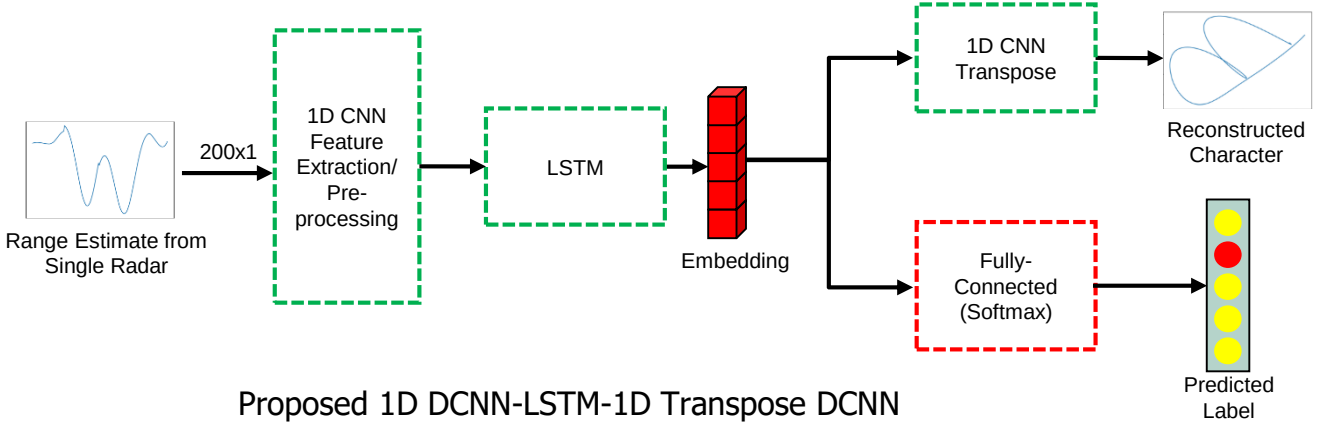
- Target localization and tracking using trilateration and $\alpha\beta$ filter
- Convolutional neural network (CNN) or long short term memory (LSTM) for recognition of the trajectories into intended characters

Limitations:

- Based on at least three radars
- Difficulty in deployment in space constrained applications
- Trilateration is dependent on the intersecting field-of-view
  - Physical placement of the radars is crucial
  - Hand occlusion
- Large network size is undesirable for embedded devices

*M. Arsalan and A. Santra, "Character Recognition in Air-Writing Based on Network of Radars for Human-Machine Interface," in IEEE Sensors Journal, vol. 19, Oct.1, 2019.

Proposed Solution

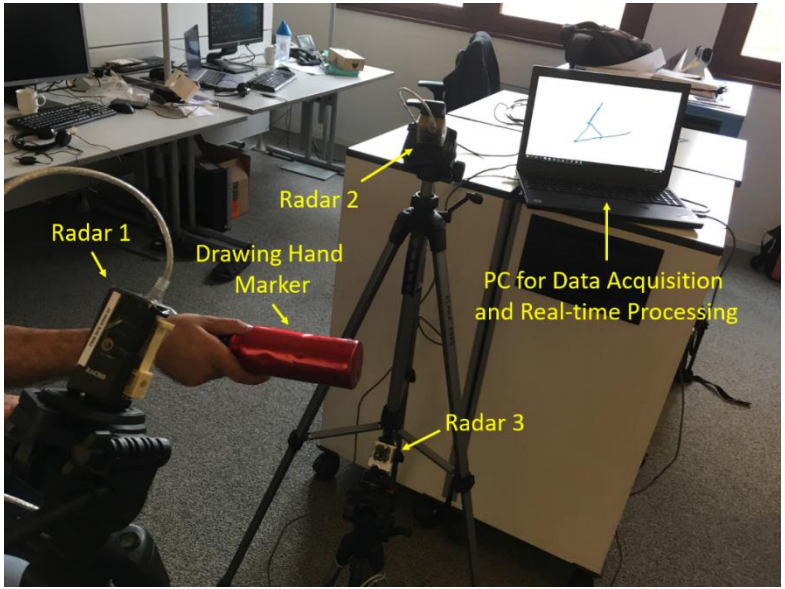


Proposed 1D DCNN-LSTM-1D Transpose DCNN

- Operates on one or two radars
- Instead of global trajectories, range information is used as input
- Joint global trajectory reconstruction and recognition of the character

Experimental Setup and Dataset

- Infineon's BGT60TR24B 60 GHz FMCW radar chipset
- Character or alphabets: A – J
- Numerals: 1 – 5
- For each character:
  - 200 samples are used for training
  - 50 samples for testing using random trials



Results (1/2)

Classification accuracy of the proposed solution to other models and baseline using three radars

Proposed Method	Avg. Accuracy (%)	Baseline*	Avg. Accuracy (%)
Single radar	90.33 ± 4.44	LSTM-CTC	93.33
Two radars	97.33 ± 2.67	BLSTM-CTC	96.67
		ConvLSTM-CTC	98.33
		DCNN	98.33

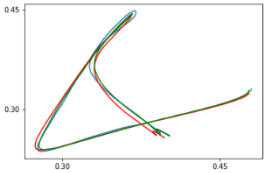
Average $L_{\_MSE}$ for reconstruction

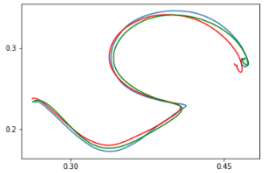
Radar configuration	Avg. $L_{\_MSE}$ (e-4)
Single radar	6.8 ± 41.5
Two radars	1.4 ± 0.7

*Baseline method

* M. Arsalan and A. Santra, "Character Recognition in Air-Writing Based on Network of Radars for Human-Machine Interface," in IEEE Sensors Journal, vol. 19, Oct.1, 2019.

Results (2/2)


Alphabet A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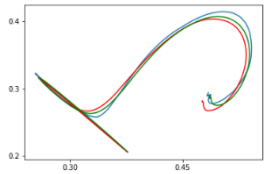
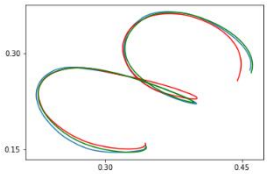

Alphabet J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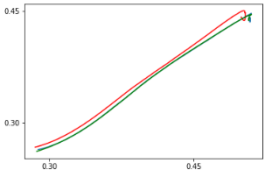
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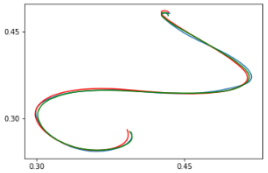
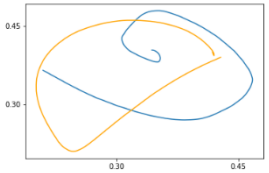
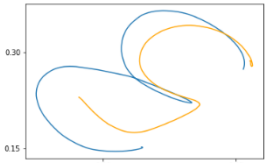
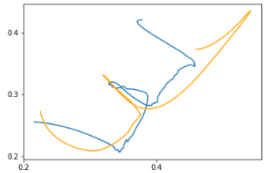

Numeral 2

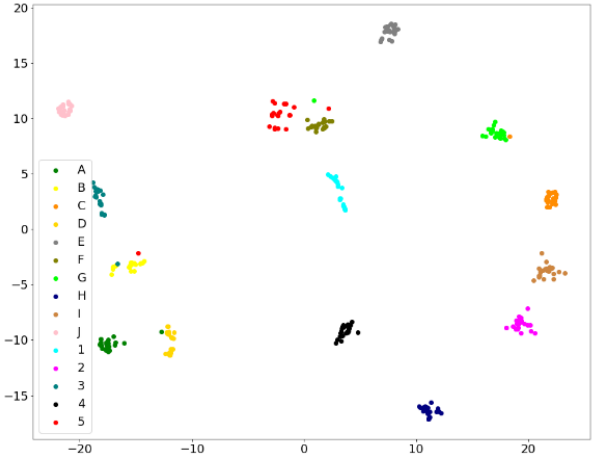
Reconstruction of some of the reference trajectories (blue) of alphabets and numerals with one radar (green) and two radars (red).


Alphabet G


Numeral 3


Alphabet E

Examples that were misclassified and wrongly reconstructed (orange). Blue represents the true label.



t-SNE of embedding learned for characters drawn in case of two radars.

Conclusions

- Air-writing offers an alternative interface to touch and keyboard interfaces to machines and can be used for augmented reality, virtual reality applications among others.
- We propose an air-writing system based on sparse network of millimeter-wave radars, i.e. strictly less than three.
- A novel 1D DCNN-LSTM-1D transposed DCNN has been proposed to reconstruct the 2D drawn image with respect to a reference and classify the drawn character.
- The proposed solution achieves:
  - 97.33 ± 2.67% classification accuracy with trajectory reconstruction error of around 1.4e-4 with two radars
  - 90.33 ± 4.44 % classficiation accuracy with trajectory reconstruction error of 6.8e-4 with one radar.
- Moreover, the proposed solution requires less memory making it suitable for low commodity hardware.

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