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

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Problem Statement/ Motivation

› Target localization and tracking using trilateration and αβ 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

Proposed Solution

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

<table>
<thead>
<tr>
<th>Proposed Method</th>
<th>Avg. Accuracy (%)</th>
<th>Baseline*</th>
<th>Avg. Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single radar</td>
<td>90.33 ± 4.44</td>
<td>LSTM-CTC</td>
<td>93.33</td>
</tr>
<tr>
<td>Two radars</td>
<td>97.33 ± 2.67</td>
<td>BLSTM-CTC</td>
<td>96.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ConvLSTM-CTC</td>
<td>98.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DCNN</td>
<td>98.33</td>
</tr>
</tbody>
</table>

### Average $L_{\text{MSE}}$ for reconstruction

<table>
<thead>
<tr>
<th>Radar configuration</th>
<th>Avg. $L_{\text{MSE}}$ (e-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single radar</td>
<td>6.8 ± 41.5</td>
</tr>
<tr>
<td>Two radars</td>
<td>1.4 ± 0.7</td>
</tr>
</tbody>
</table>

*Baseline method


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

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:
  - $97.33 \pm 2.67\%$ classification accuracy with trajectory reconstruction error of around $1.4e^{-4}$ with two radars
  - $90.33 \pm 4.44 \%$ classification 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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