ENHANCING BEAMFORMED FINGERPRINT OUTDOOR POSITIONING WITH HIERARCHICAL CONVOLUTIONAL NEURAL NETWORKS

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Introduction

Problem: How to incorporate the spatial properties of the mmWave outdoor positioning problem into a neural network model?

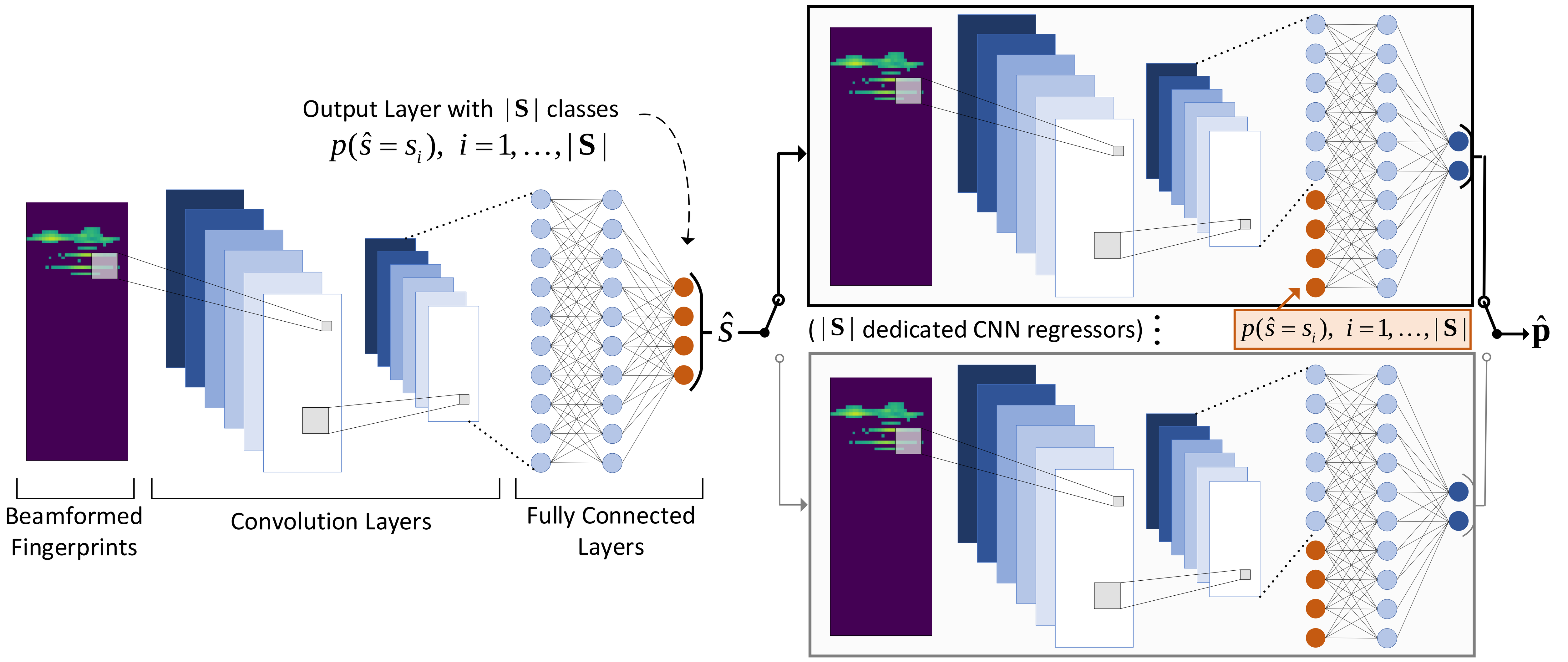
Motivation

- In [1], we proposed a CNN-based localization system, based on beamformed fingerprint (BFF) inputs;
- The BFFs are obtained from a sequence of codebook-based beamformed mmWave transmissions;
- While the BFFs were designed with spatial properties in mind, the used model was a standard CNN.

Proposed Approach

- As with other positioning methods, adjacent positions are expected to have similar input signals;
- Due to mmWaves, the BFFs will have some noticeable discontinuities throughout the considered area;
- We propose to use a hierarchical model to take advantage of these two distinct properties.

Proposed System



- For each base station, the covered area can be seen as a set of sub-areas $\mathbf{S}$ ($\mathbf{S} = \{s_1, \ldots, s_{|\mathbf{S}|}\}$);
- The first part of the hierarchical model is a classification model that focuses in detecting the received BFF's sub-area $\hat{s}$, which is aided through the aforementioned discontinuities;
- The second part of the hierarchical model consists on a set of $|\mathbf{S}|$ regression models, one per sub-area, where the final position estimate is given exclusively by the model associated with $\hat{s}$;
- Each of the $|\mathbf{S}|$ regression models is specialized in its sub-area, allowing the complete model to better distinguish adjacent positions;
- To allow the regression to partially recover from errors during classification, the softmax output of the classification model is also used as an input of the regression models.

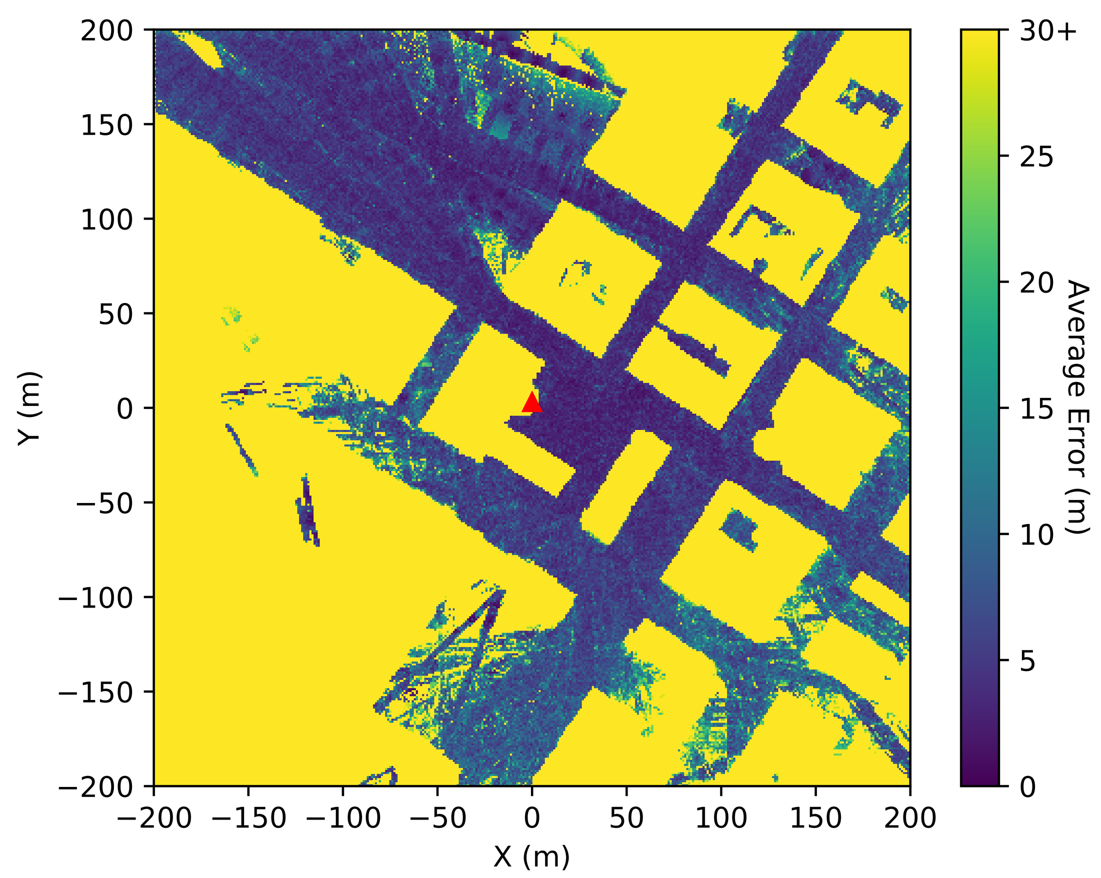
Simulation Results

Simulation Apparatus

Parameter Name	Value
Carrier Frequency	28 GHz
Transmit Power	45 dBm
Codebook Size	32 (155° arc, 5° between entries)
Receiver Grid Size	160801 (400 × 400 m, 1 m above the ground)
Convolutional Layers	1 layer (8 features with 3 × 3 filters, 2 × 1 max-pooling)
Hidden Layers	12 (256 neurons each)
Class. Output	Softmax with $|\mathbf{S}|$ classes
Regression Ouput	2 Linear Neurons (2D position)
Added noise	$\sigma = [2, 10]$ dB (Log-Normal)
Assumed Rx. Gain	10 dBi
Detection Threshold	−100 dBm

- Propagation simulated through ray-tracing – the simulations matched experimental measurements at the NYU campus;
- BFFs obtained from the simulations, for 160801 positions;
- The $|\mathbf{S}|$ sub-areas are created from successive bisections of both dimensions of the considered 2D area;
- The classification and the $|\mathbf{S}|$ regression models share the same hyperparameters.

Results



Results in [1]

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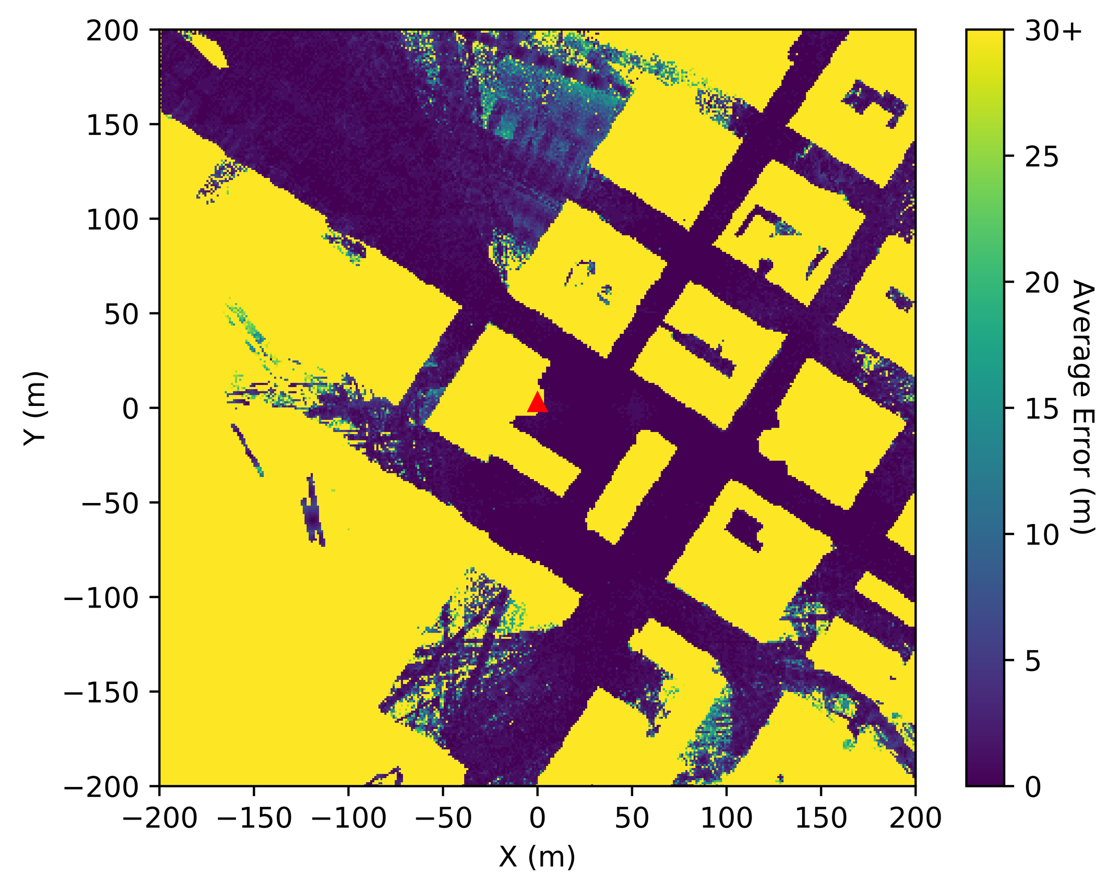

Obtained results with $|\mathbf{S}| = 64$

Conclusions: we obtained a 55% average error reduction when compared to our previous work. This sets a new state-of-the-art performance level for non-line-of-sight mmWave outdoor positioning, with an average error as low as 3.31 m.

GitHub:

Bibliography and Acknowledgements

[1] J. Gante *et al.*, "Beamformed Fingerprint Learning for Accurate Millimeter Wave Positioning", *IEEE 88th Vehicular Technology Conference (VTC Fall)*, 2018.

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