Joint Communication and Sensing (JCAS) based Object Identification using Machine Learning

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Outline

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2. Background
3. Simulation Setup
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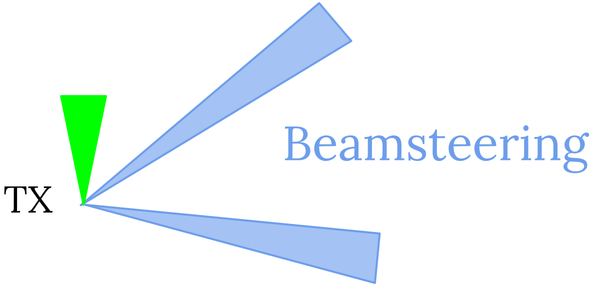
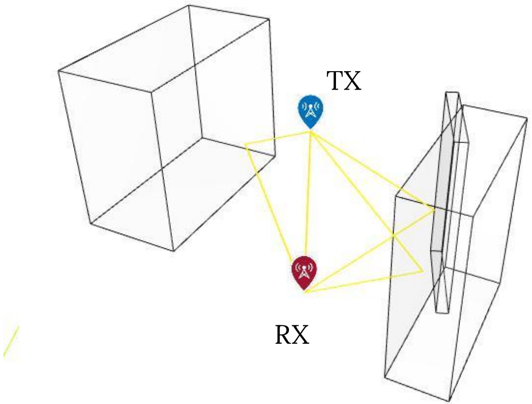
Motivation

- 6G - JCAS: Joint Communication and Sensing, Integrated Communication and Sensing, Joint Communication and Radar
- JCAS: communication and sensing together in one system and frequency spectrum
  - applications: communication link optimization, intrusion and proximity detection, gesture detection ...
- Machine Learning as central aspect of 6G

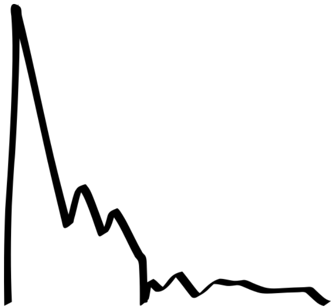
Problem

Scenario:

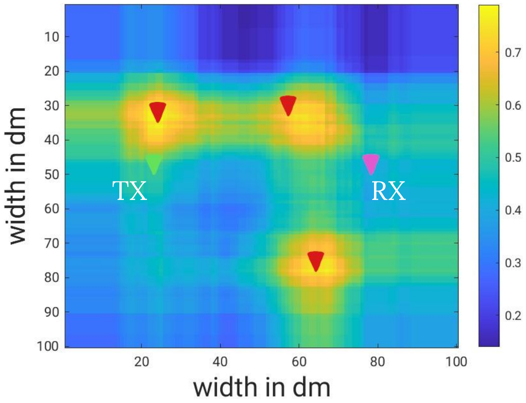




Channel Impulse Responses



Object Localization

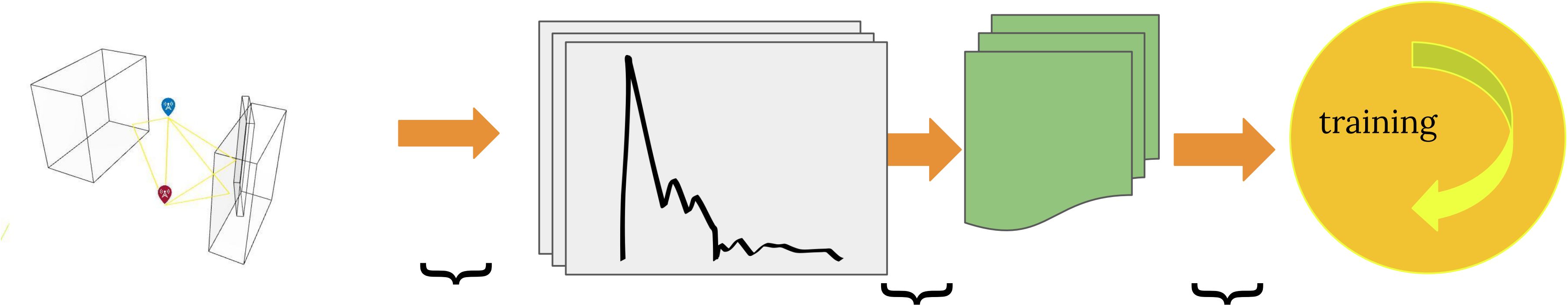


Idea / Intuition

Room Representation

Estimated
Channel Impulse Responses

Training Data for Machine
Learning Model



Simulation of
Propagation

Feature Extraction

Training

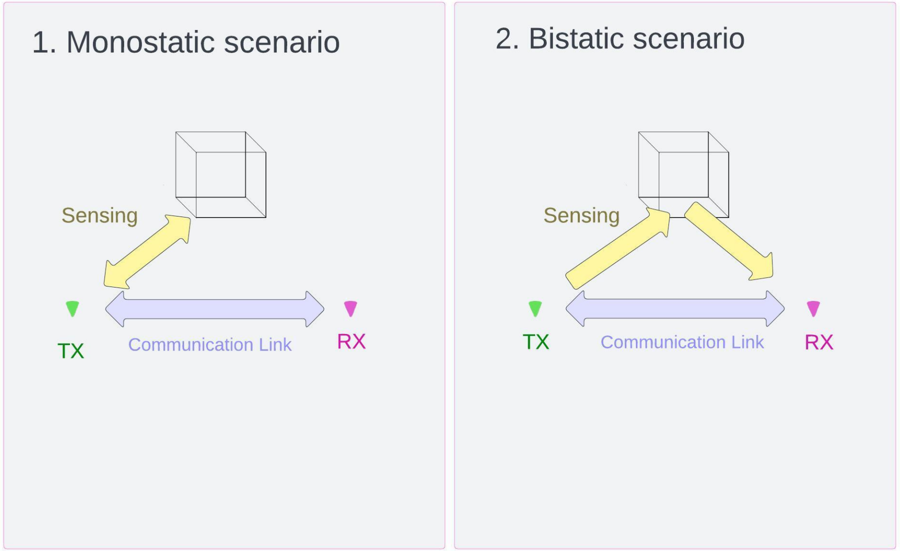
Trained Model

Background

- Bistatic Joint Communication And Sensing
- related work:
    - Object localization

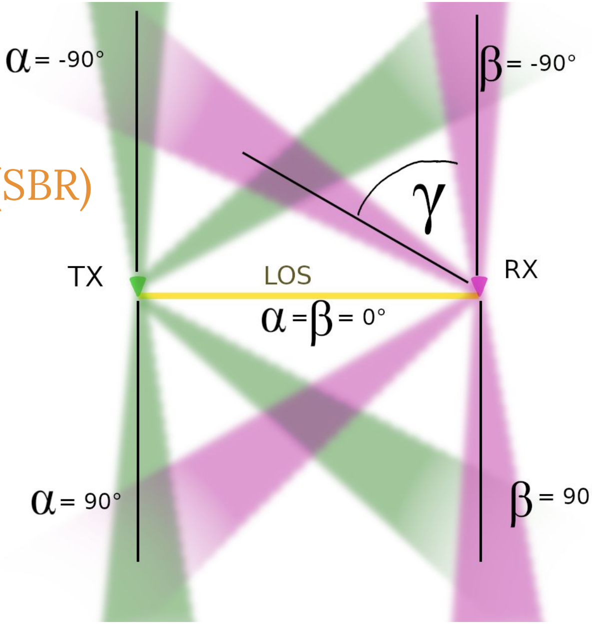
in other frequencies, e.g. audio

- mmWave RADAR
- ...



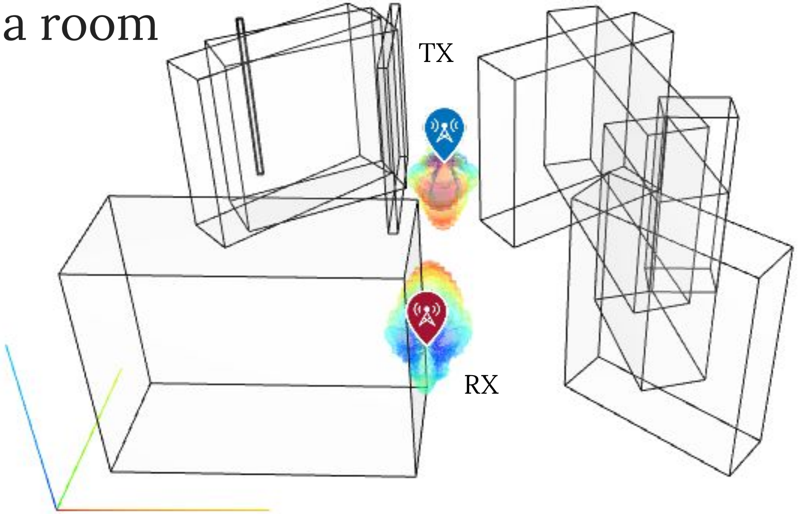
Simulation Setup

Number of TX/RX	1
Signal:	Pseudo Noise Sequence
Distance between TX and RX:	5,5m
Antenna:	Horn antenna
Mechanical beam steering:	x angles per device
Simulation method:	MATLAB's Raytracing (SBR)
Frequency:	60GHz
Scenario:	Line of Sight



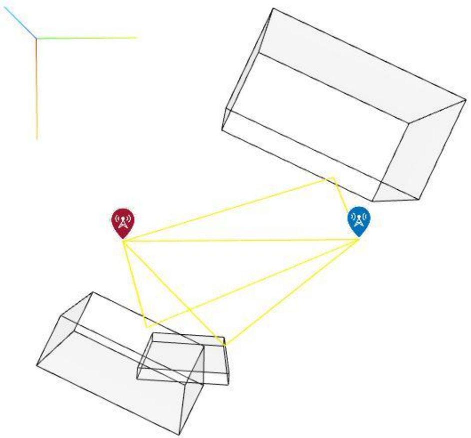
Simulation Setup - Limitations

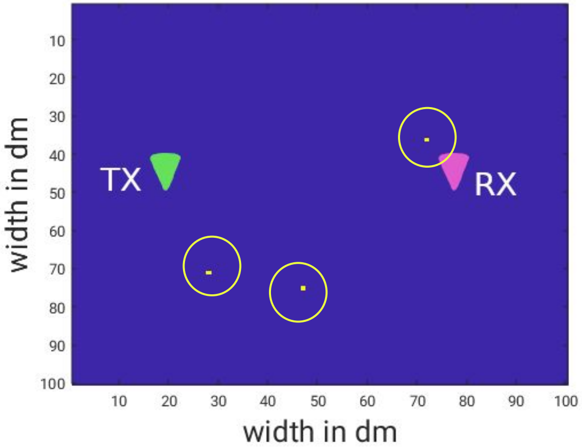
- no permeability of objects
- only first order reflections
  - no higher order reflections
  - no diffractions
  - no scattering-effects
- same surface-material for all object in a room
  - plasterboard
  - metal



Data Generation - Raytracing

- MATLAB
- Method : SBR (shooting and bouncing rays)
  - approximate number of propagation paths
  - exact geometric accuracy
- Only reflections (no diffractions)
- launched rays: 655,362



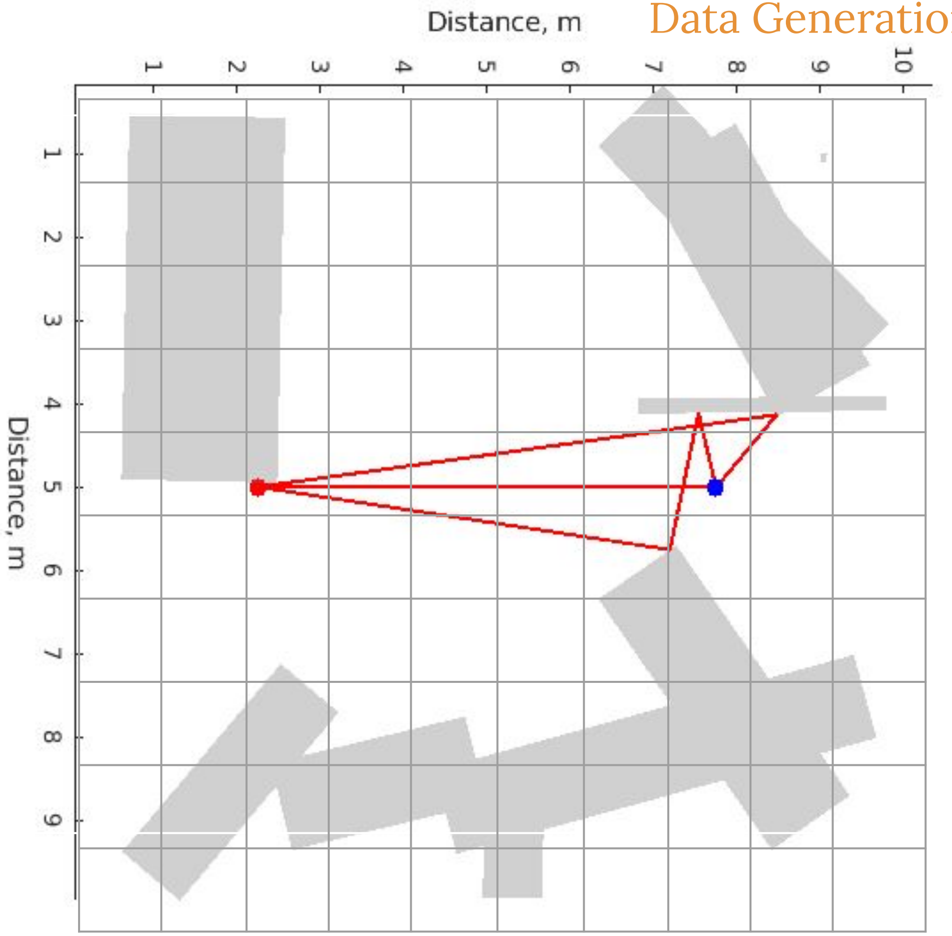


Data Generation

- Room Model:
- 2D grid
  - 100 x 100 grid-units
  - fixed position for RX and TX
- TX-position [50, 22.5, 1]
- RX-position [50, 77.5, 1]
- results for static room

  of 10m x 10m:

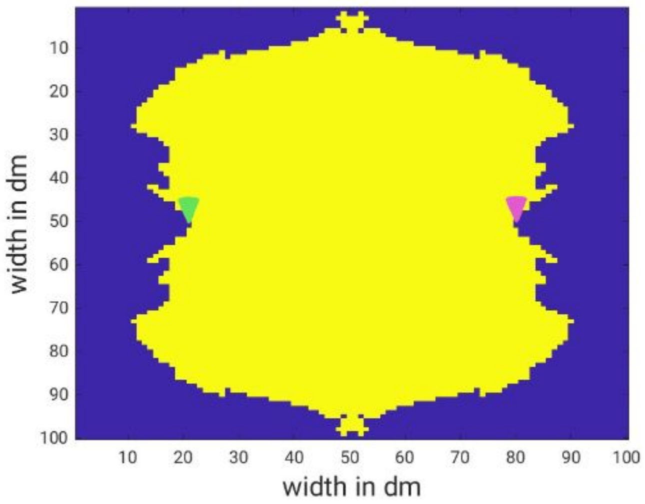
  - TX [5, 2,25, 1]
  - RX [5, 7,75, 5, 1]
  - 10cm "stepsize"



Data Generation - Sensing Area

- plasterboard and metal
- yellow: "Sensing Area"
    - maximal influence of an object above a threshold
- blue: "ignored" area

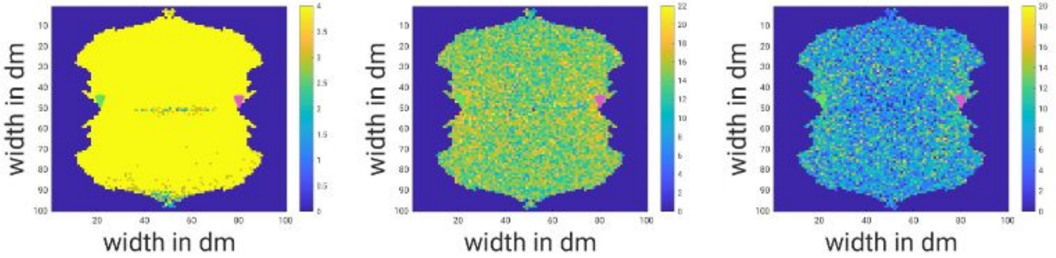
Sensing Area for -90° - 90°, angular step of 30′



Threshold for "Sensing Area"

Material	Threshold for object influence
plasterboard	0.001
metal	0.025

Distribution of reflection-points in datasets



(a) one-object-rooms (b) two-object-rooms (c) three-object-rooms

Data Generation - Input Vector

- position in grid
- for each angle-pair: maximal gain + time point of maximal gain
- 1 for object, 0 for no object
- 20% testdata

X	Y	max Gain 1	time 1	max Gain 2	time 2	maxGain 3	…	Probability
35	21	0.001	82	0.02	21	0.009	…	1
34	56	0.001	82	0.02	21	0.009	…	0
25	77	..	..	..	..	..	…	..

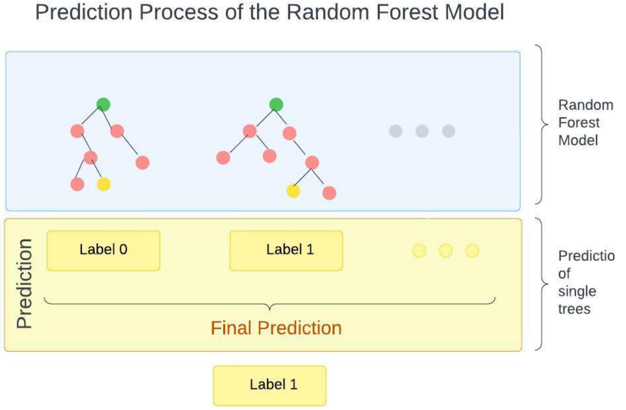
Results

Selection of Machine Learning Model

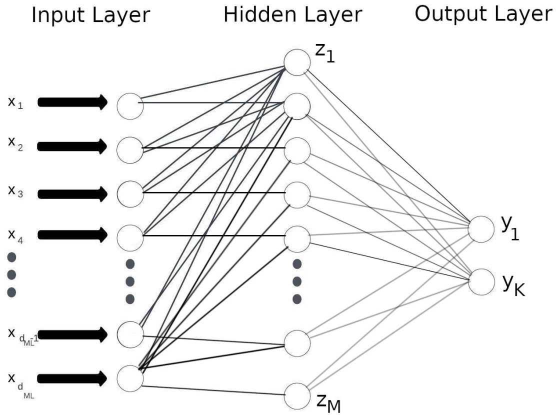
Results of Classification Learner		
name of model	**accuracy**	**comments**
Fine Tree	78.8%	
Narrow Neural Network	98.0%	
Medium Neural Network	98.9%	
Wide Neural Network	99.3%	
Gaussian Naive Bayes	60.4%	
Neural Network	99.0%	3 layers of size 11
Bagged Trees	99.1%	

Testing of different Models in MATLAB

Random Forest Model



Multilayer Perceptron



Experimental Verification

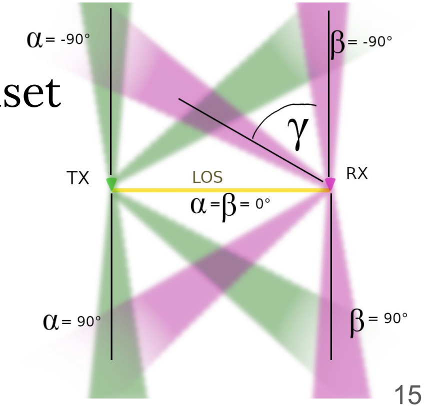
- Trained Models:
  - **Random Forest Model**
  - **Multilayer Perceptron Model**
- Characteristics of Training Data:

Material	SNR in dB	Angular span	Angular step γ	Number of objects
metal, plasterboard	Inf, 30, 20, 10	-90° to 90°	60°	1, 1-3, 3
metal, plasterboard	Inf, 30, 20, 10	-90° to 90°	30°	1, 1-3, 3
metal	10	-63° to 63°	14°	1-3
metal	10	-91° to 91°	14°	1-3
metal	10	-77° to 63°	28°	1-3

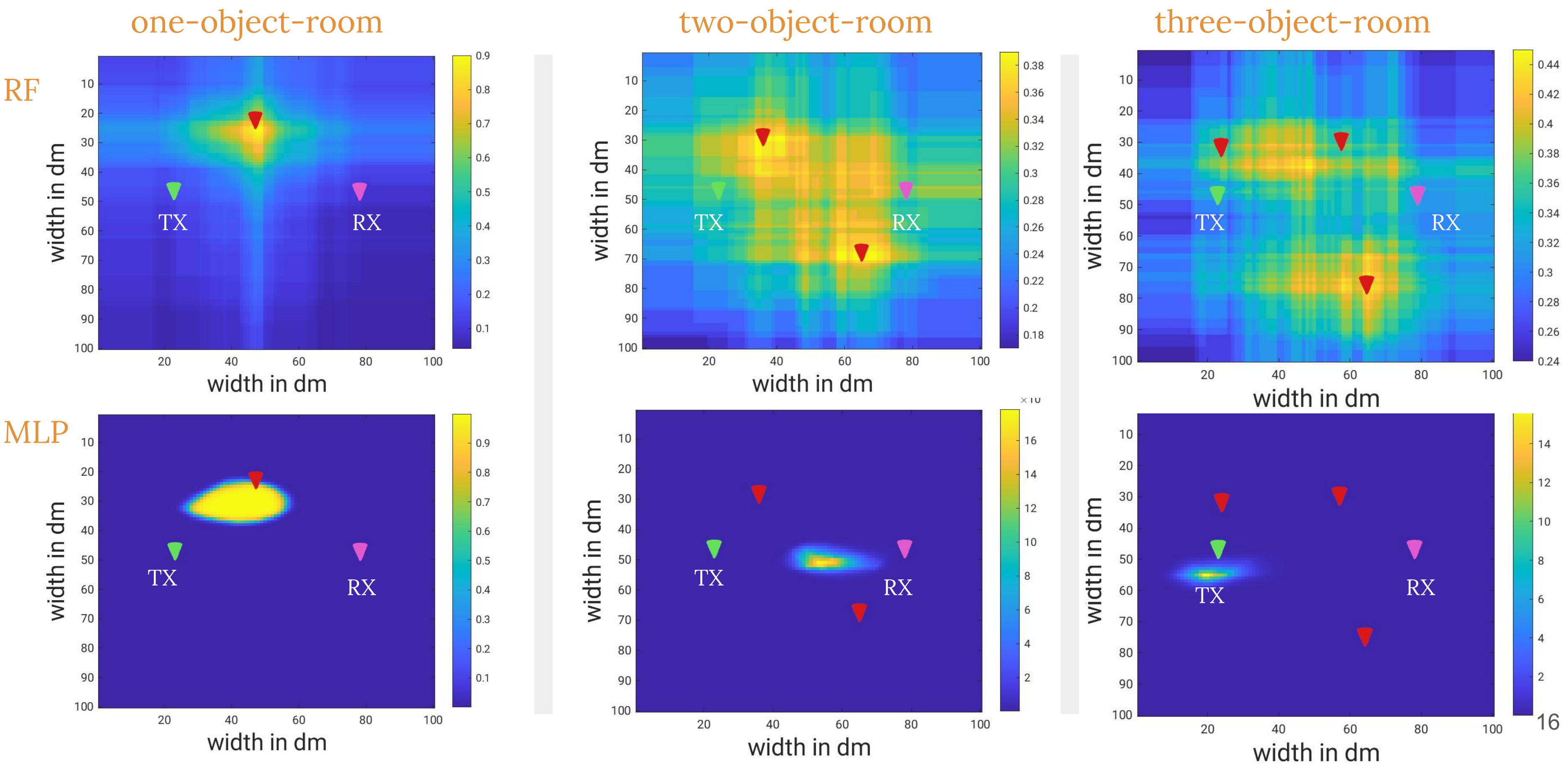
- Tested on simulated data
  - constructed the same way as training data
  - whole "room", all positions for visualization
- Tested on experimental data
  - data from anechoic chamber

Evaluation on simulated data

- Angular step of 30° and 60°, angular span from -90° to 90°
- Accuracy, Precision and Recall
  - SNR: minor influence
  - Material: minor influence (metal > plasterboard)
  - 90° and 60° angular close in quantitative analysis
  - High Recall values + low precison -> False Positives
  - Best results: trained on single-object rooms, tested on single object rooms
    - 0.97
  - Most robust: one to three objects in training dataset
  - Issue: unknown number of objects
  - Importance of classification threshold

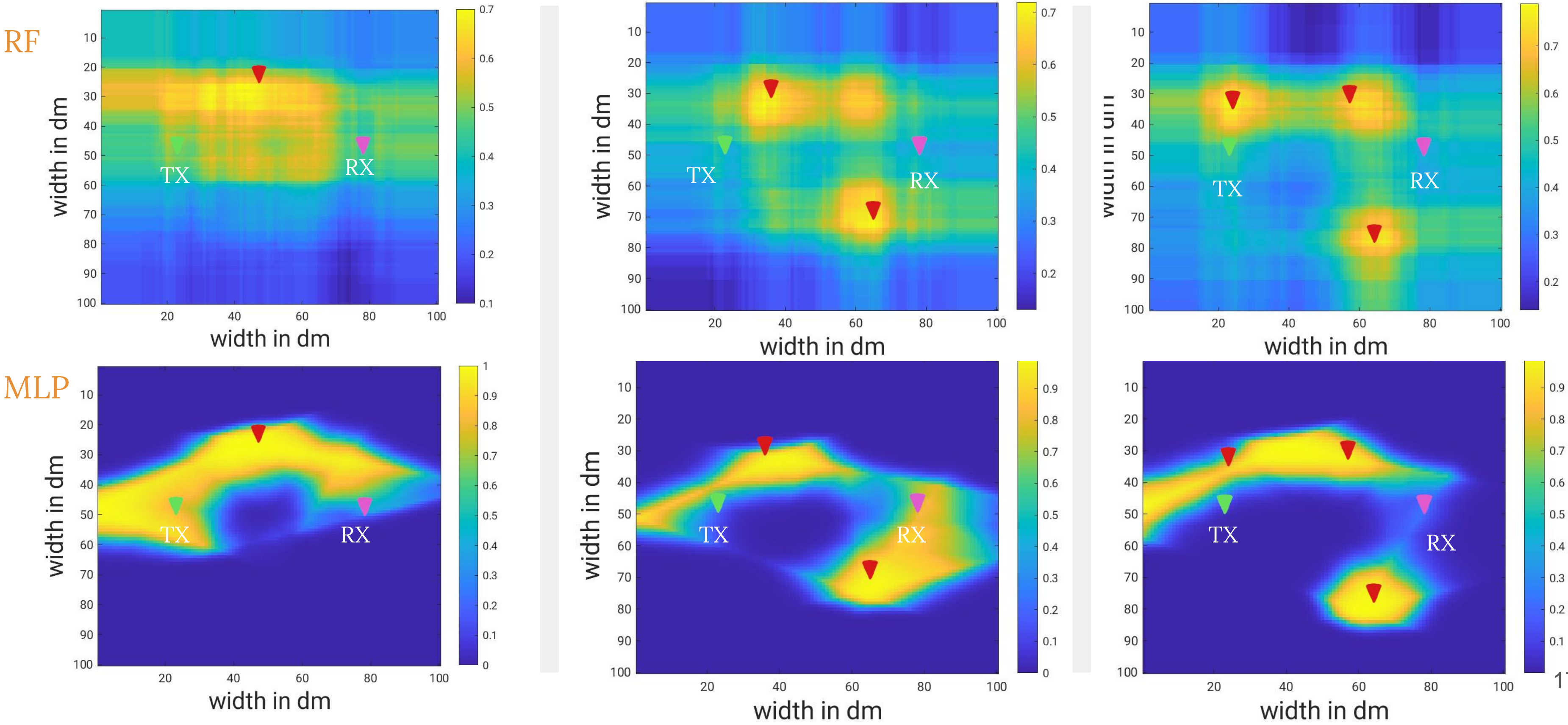


Results - trained on single-object rooms

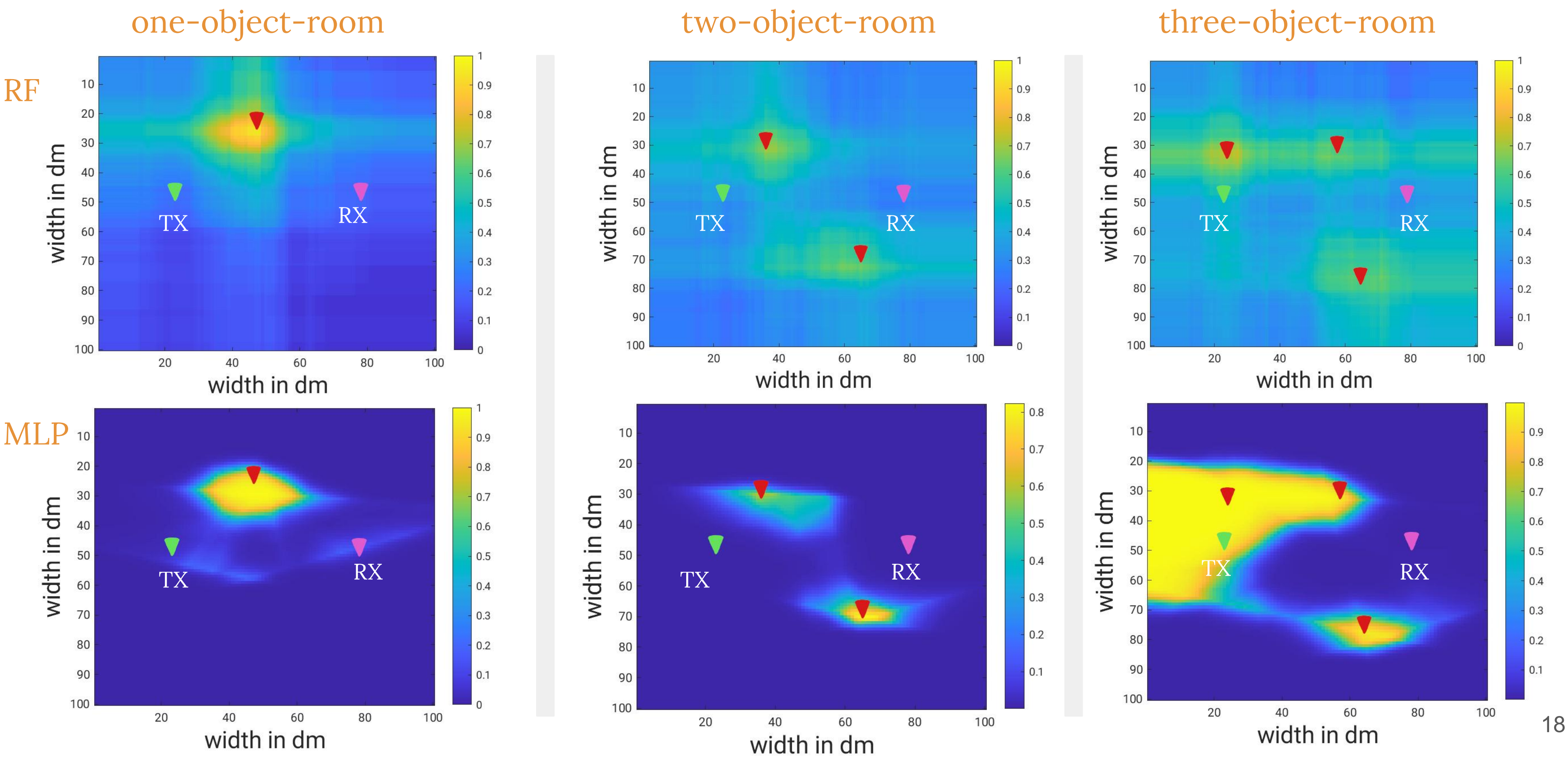


Results - trained on three-object rooms

one-object-room | two-object-room | three-object-room



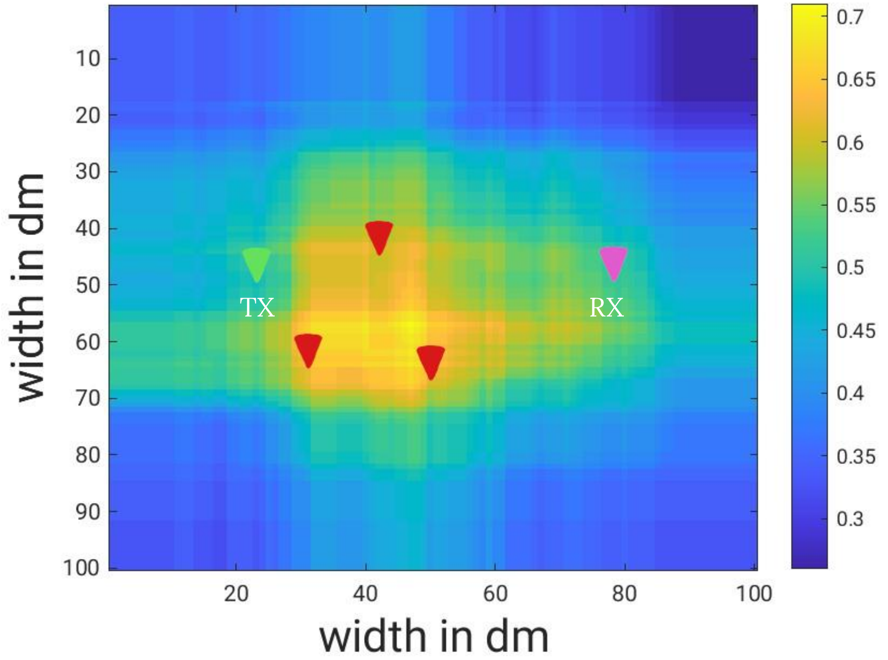
Results - trained on one - three object rooms



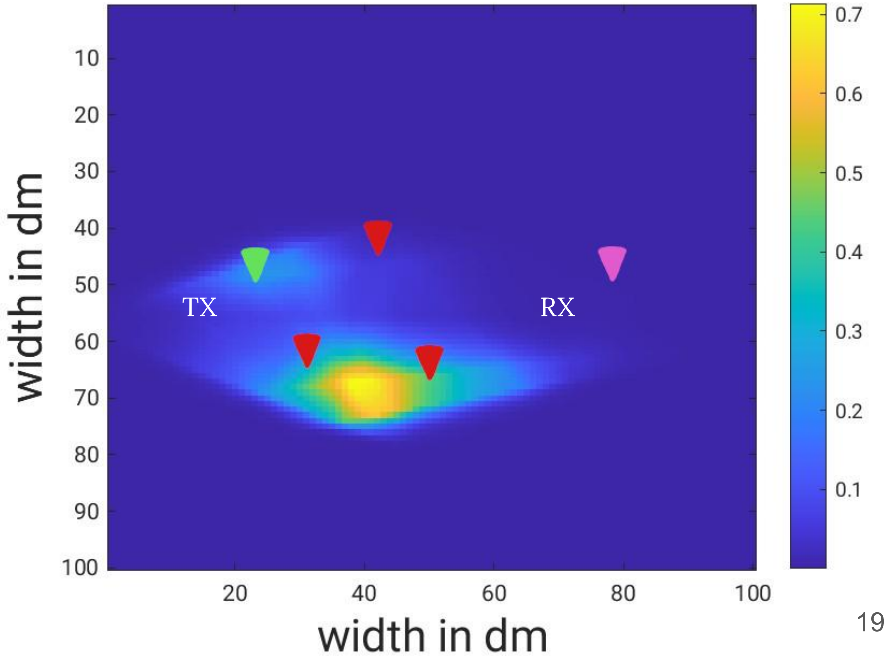
Results - experimental data

- trained on one-two-three-object rooms
- material metal

Random Forest Model



Multilayer Perceptron Model



Conclusion

- low impact of SNR value
- unseen number of objects harder to predict
- less accurate on experimental data then numerical approach

Extensions:

- different machine learning models
- simulation setup - including scattering
- higher order reflections
- experimental data with a lower SNR value for testing
- different surfaces ...