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Fast super-resolution Burg algorithm for increasing the radar angular resolution

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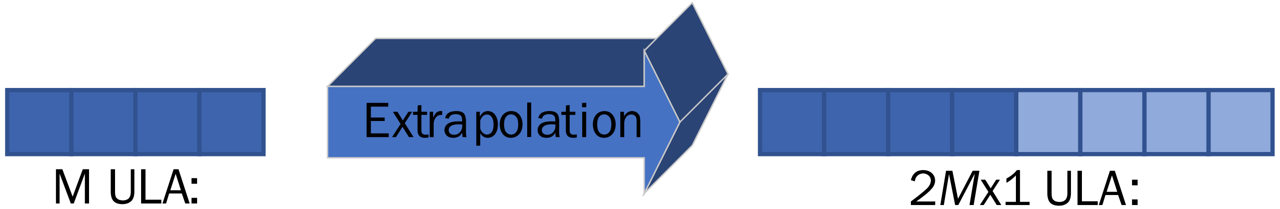
Introduction

- For imaging radars, angular resolution plays an increasingly important role.
  - For example, in automotive, aviation, people tracking and life sign monitoring, where constrains for radar size, complexity and latency are strict.
- The spatial resolution is directly dependent on the size of the antenna aperture.
- Large antenna array systems have a bottleneck of high complexity in both hardware and in software sense,
  - high hardware cost,
  - energy consumption,
  - a serious heat dissipation problem.
- The size of the MIMO radar should be as large as possible and the number of radar channels should be as small as possible.

Extrapolation algorithms

- There are two solutions to this problem: extrapolation algorithms and aperiodic array
- Extrapolation algorithms extend the measurements from a small antenna array to a much larger virtual array through signal processing.
- Signal extrapolation algorithms are very well studied in the field of spectral estimation.
  - Autoregressive (AR) models: covariance, modified covariance, Yule-Walker, and Burg.
  - The AR model predicts the time series data at a certain time from the linear sum of the previous data.
  - Burg technique has high resolution for short data records and it produces always a stable model.
  - Other AR models, like as covariance and modified covariance AR models produce unstable models and Yule-Walker model performs well only for large data records.



M ULA:
4 physical elements

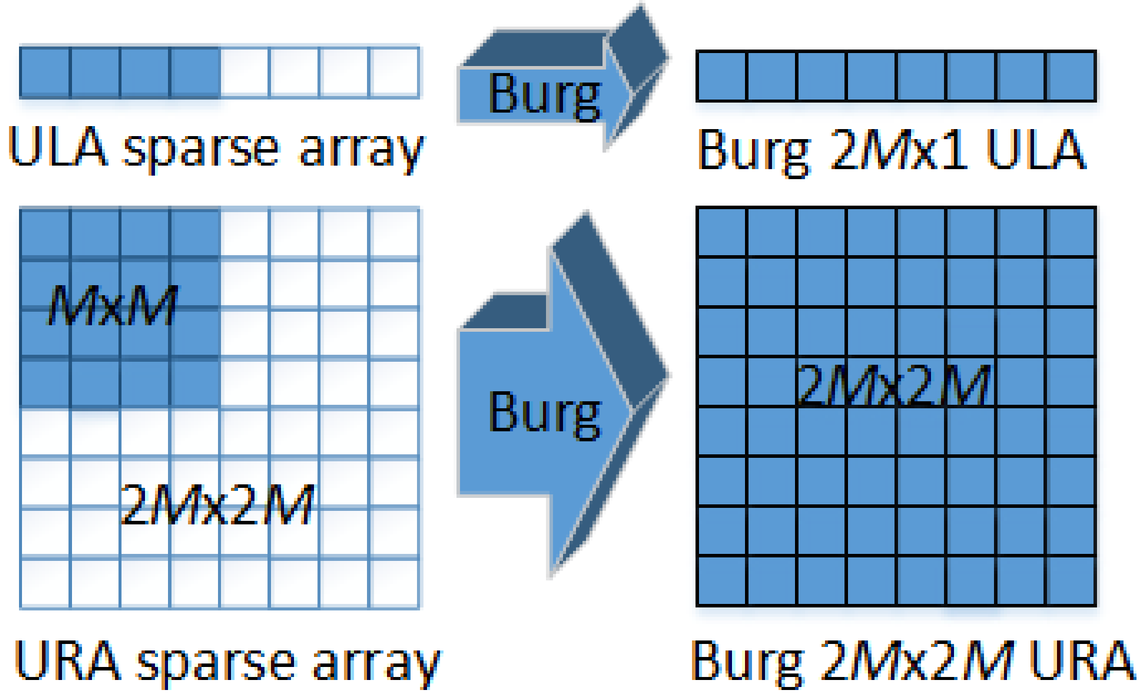
2*M*x1 ULA:
4 physical elements and
4 extrapolated elements

Burg algorithm

- Burg algorithm is a known way to predict how a signal continues based on extrapolation.
- It predicts the AR coefficient using the least squares method.
- The principle of the AR model is defined as follows:

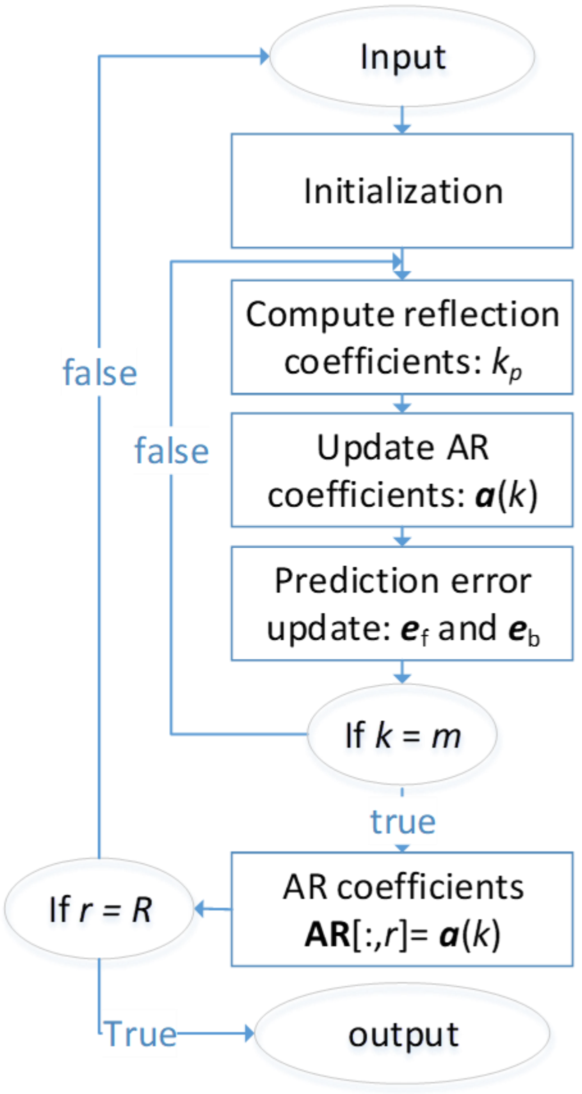
$$x_t = \sum_{k=1}^{m} a_k x_{t-k} + w_t$$

  - x_t is time series
  - a_k is AR coefficient
  - m is AR order,
  - w_t indicates the prediction error between the linear sum of the past data and the actual current data.



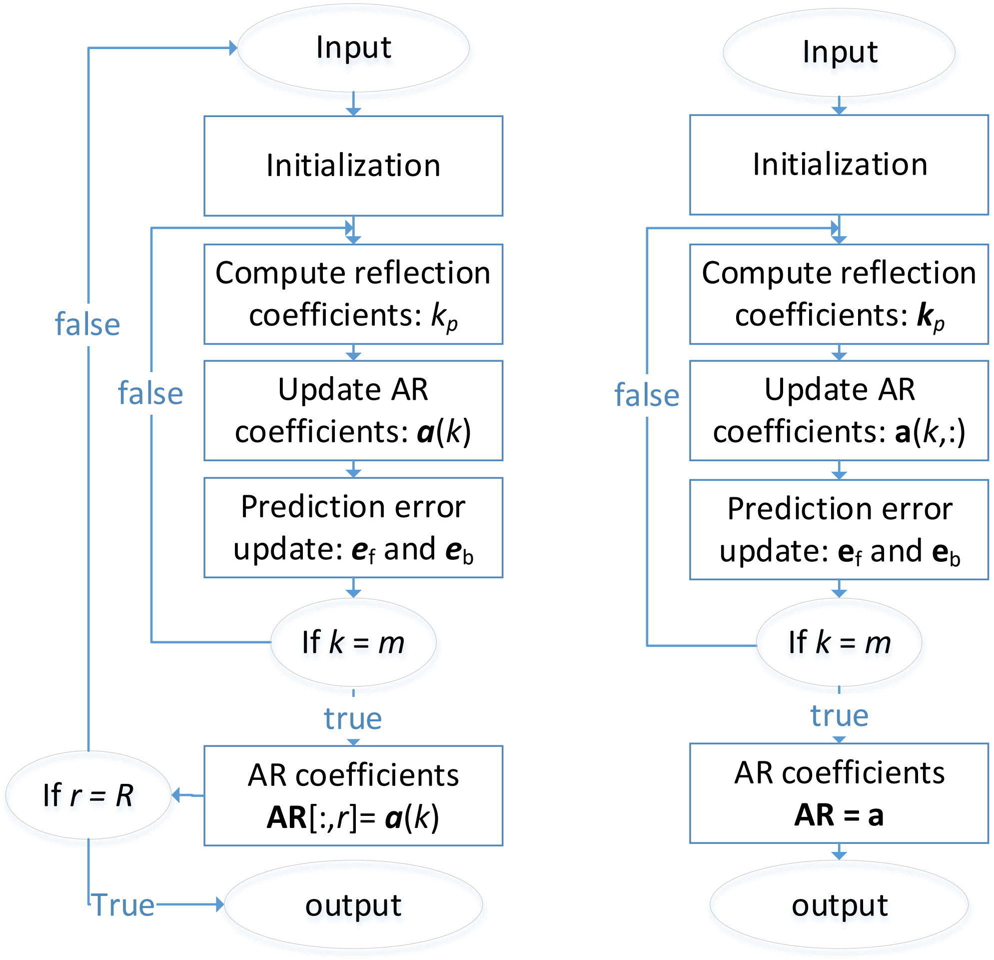
Burg algorithm

- Burg algorithm can be readily found for example in Mathworks and Python spectrum libraries.
  - The problem of the conventional Burg algorithm, which is used in libraries, is that it is too time-consuming for radar where each range bin, *r*, must be calculated individually.
  - This procedure take too much time, frames per second (fps) is 2.
  - It is too slow for the real-time application.



Fast Burg algorithm

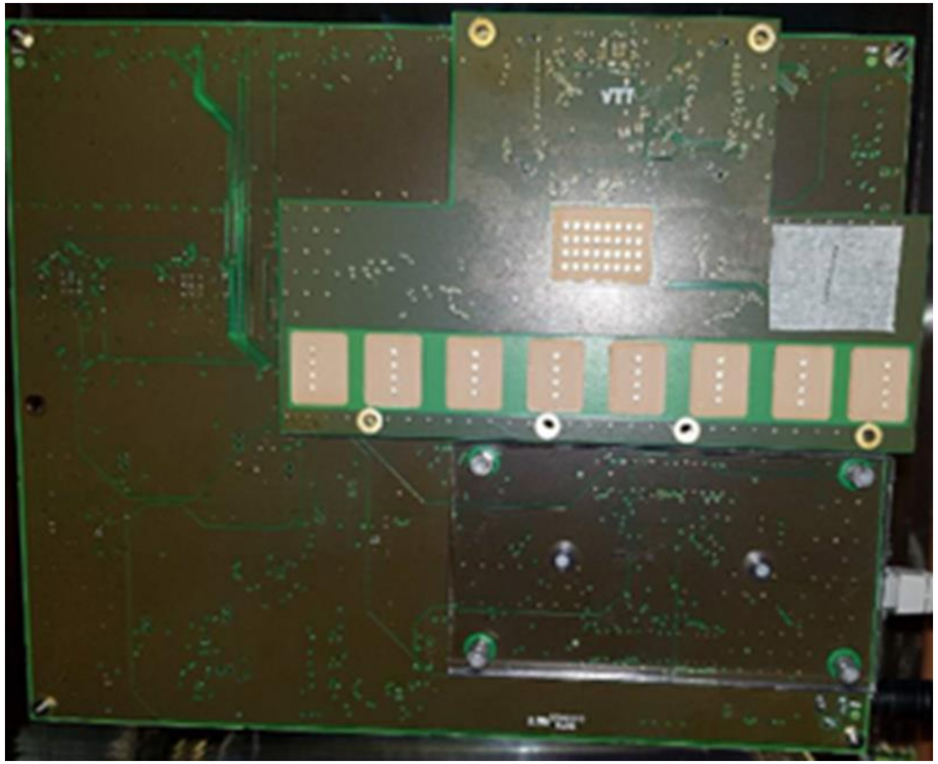
- Our fast Burg algorithm utilizing matrix multiplication that we can estimate all range bins at the same time.
  - We have improved the calculation time considerably.
    - The performance is enhanced from 2 fps to 29 fps
    - It is 14.5 times faster compared to the conventional Burg algorithm, when 64 radar channels was used, and the AR order was 48.
  - Our new fast Burg algorithm can be used in real time measurements.



(a) Burg (b) Fast Burg

FMCW 60 GHz MIMO radar

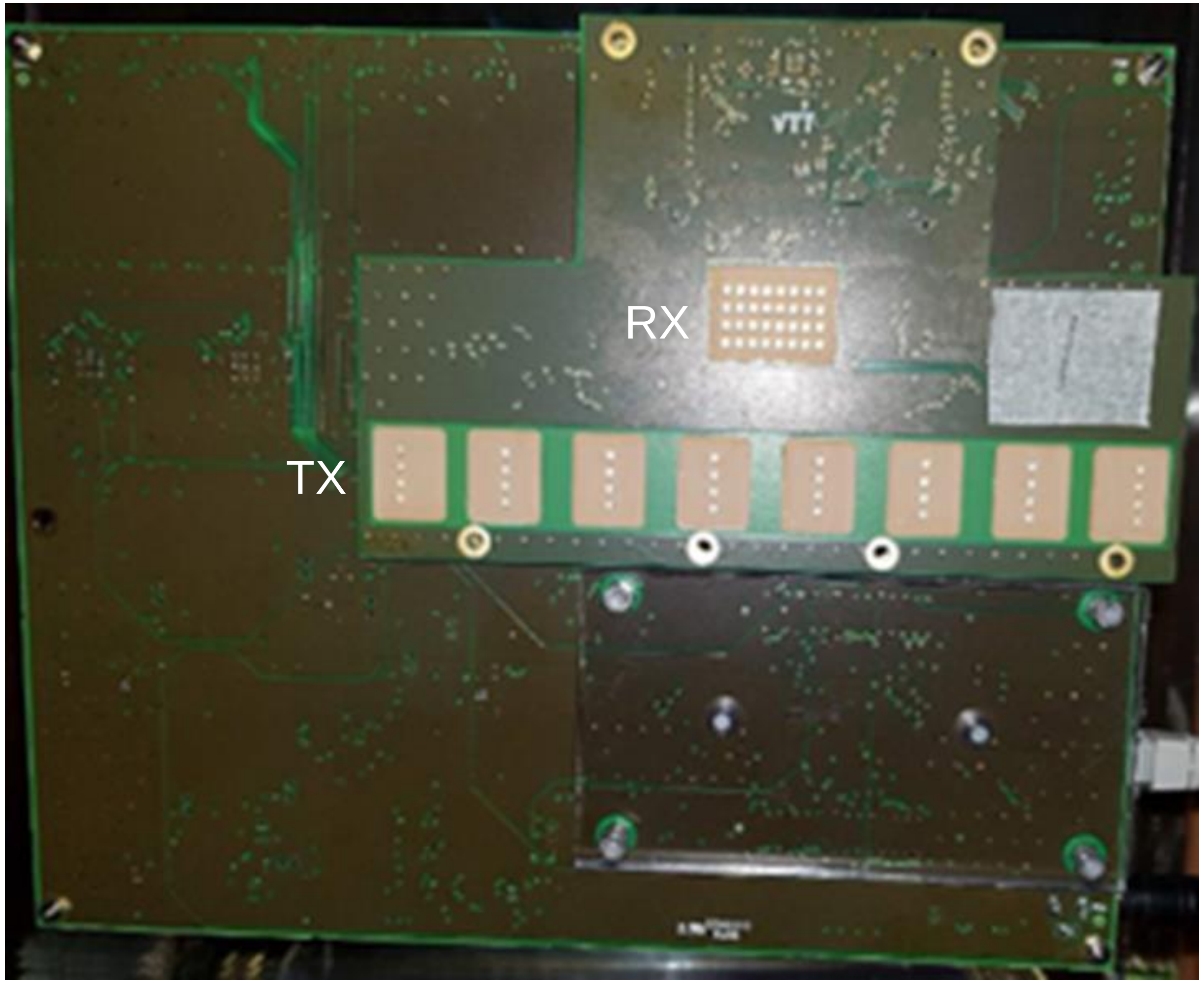
- The VTT’s MIMO frequency modulated continuous wave (FMCW) radar operates at 60 GHz and is based on our own modular chipsets.
  - Manufactured with SiGe technology at IHP Microelectronics
  - Modulation capabilities
  - Frequency MIMO technique allowing the detection of moving targets.



60 GHz MIMO radar's parameters

- The FMCW chirp bandwidth was considered 5 GHz.
- The range resolution is 3 cm.
- The angular resolution is 1.87° at the antenna boresight.

Parameters	Number of channels	Distance between channels
TX channels	8	8λ/2
RX channels	8	λ/2
Virtual channels	64	λ/2

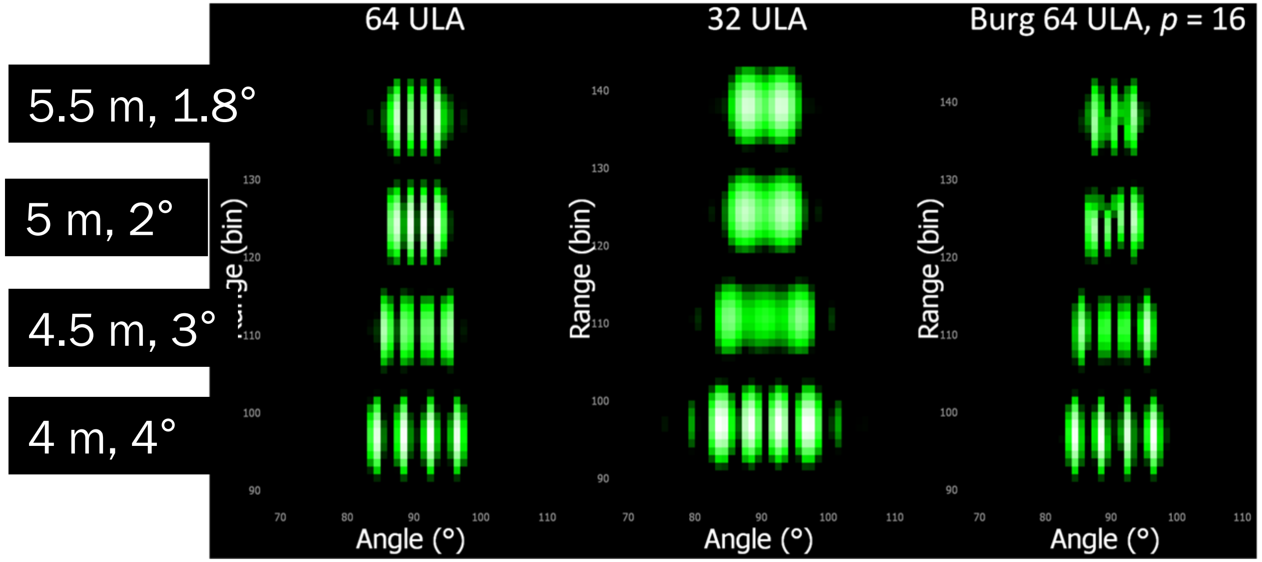


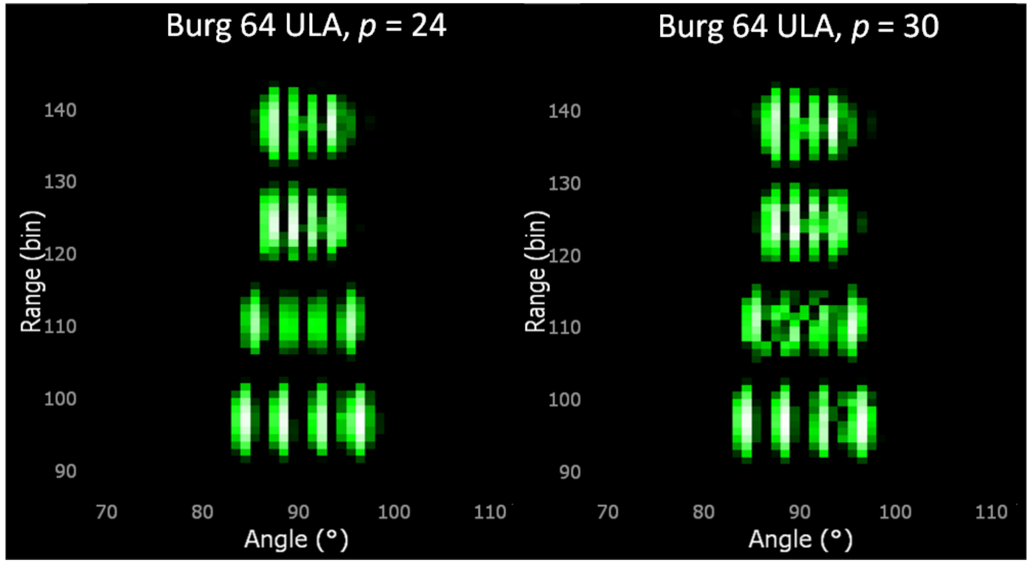
Results

- The fast Burg algorithm is verified in simulation and experimental measurements our VTT's in-house 60 GHz MIMO radar and compared to a MIMO array of same size.
- Burg and other AR models requires that the number of the AR order has to be p < M, where M is the number of the radar channels.
- Many authors have been suggested for Burg algorithm that $p \leq M/2$, because the linear prediction spectral estimate may exhibit spurious peaks, if order exceed half of the number of data points for short data segment.
- In other hands, if higher AR order is used, we can achieve better results.
- We have also tested the algorithm with different orders.

Simulation results: ULA array

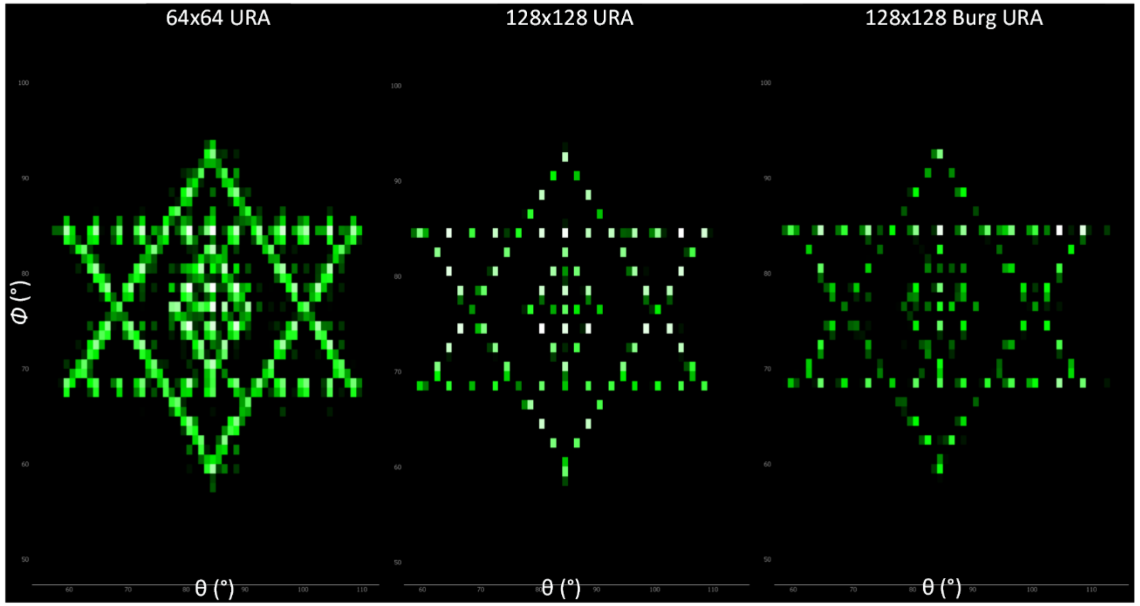
- Theoretical angular resolution is 3.8° for 32 ULA and 1.8° for 64 ULA.
- By using Burg algorithm, the 2° resolution is achieved if *p* = 16 and 1.8° resolution if *p* = 24.
- If the number of the order is too long, the spurious speaks may be start to appear.
- The fast Burg algorithm was able to separate the same closely spaced targets with *M* virtual channels as the dense ULA MIMO radar with *2M* channels.
- The proposed algorithm is 14.5 times faster than the conventional Burg method, almost double the radar angular resolution.



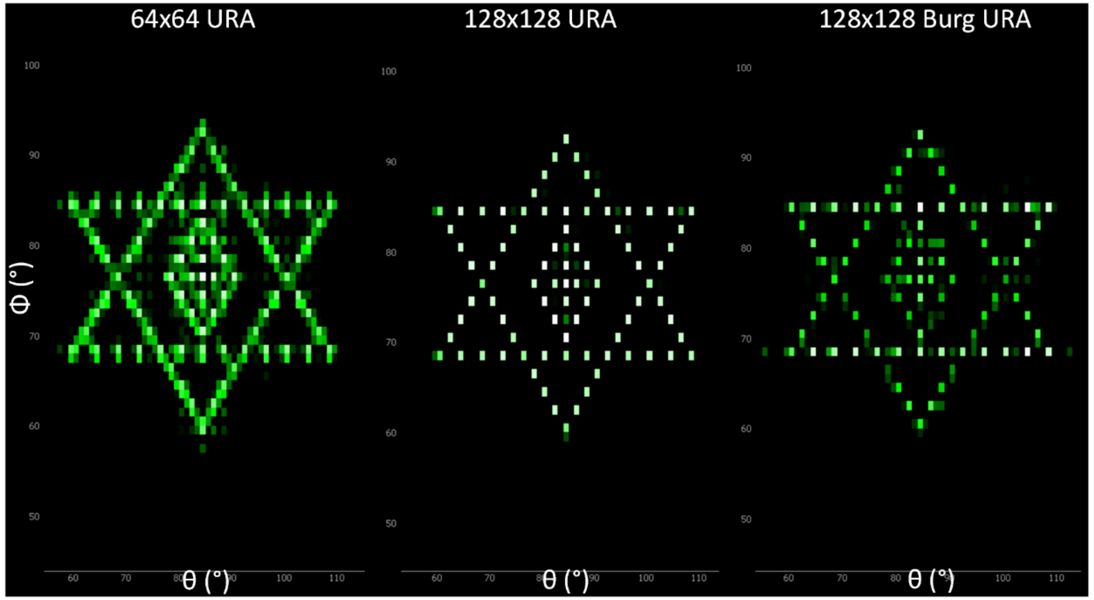


Simulation results: URA array

- We have also modelled Burg algorithm for 64x64 URA, with different AR order values: p = 32 and 37.
- However, if the order is increased to 37, we can note that spurious speaks start to appear.
- In summary, the Burg algorithm can separate the same closely spaced targets with *MxM* channels as the dense URA with 2*M*x2*M* channels.



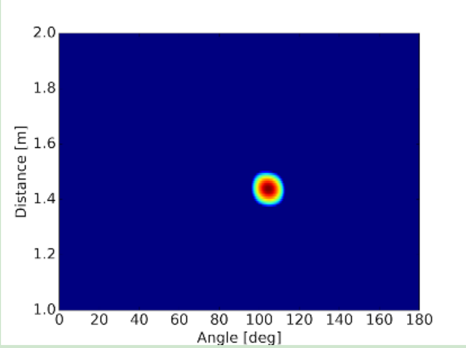
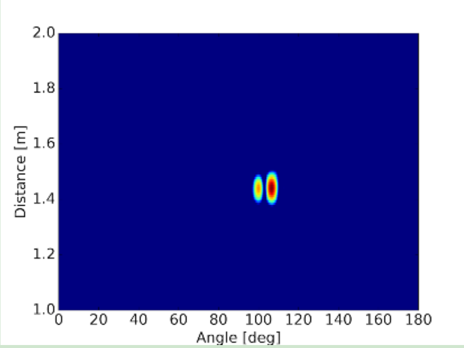
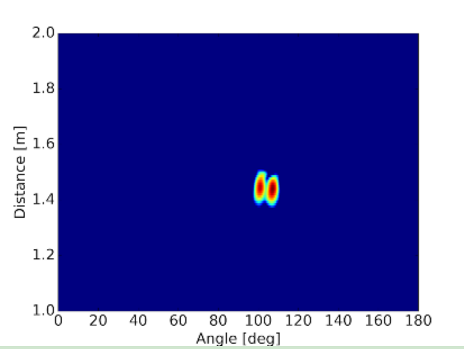
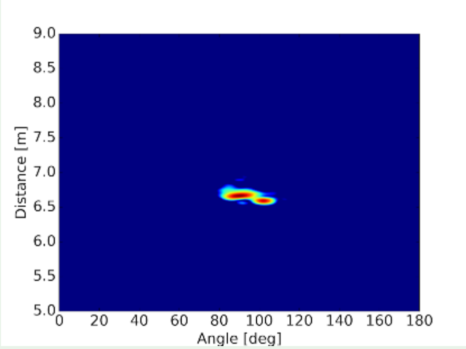
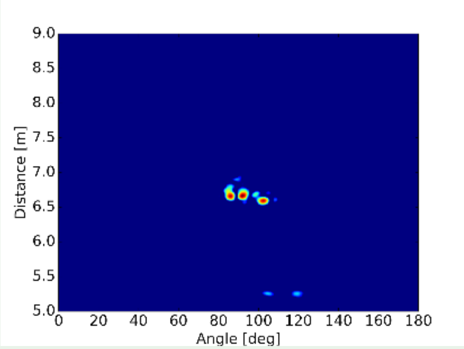
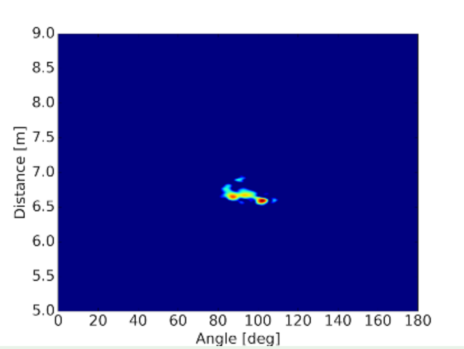
(a) p = 32



(b) p = 37

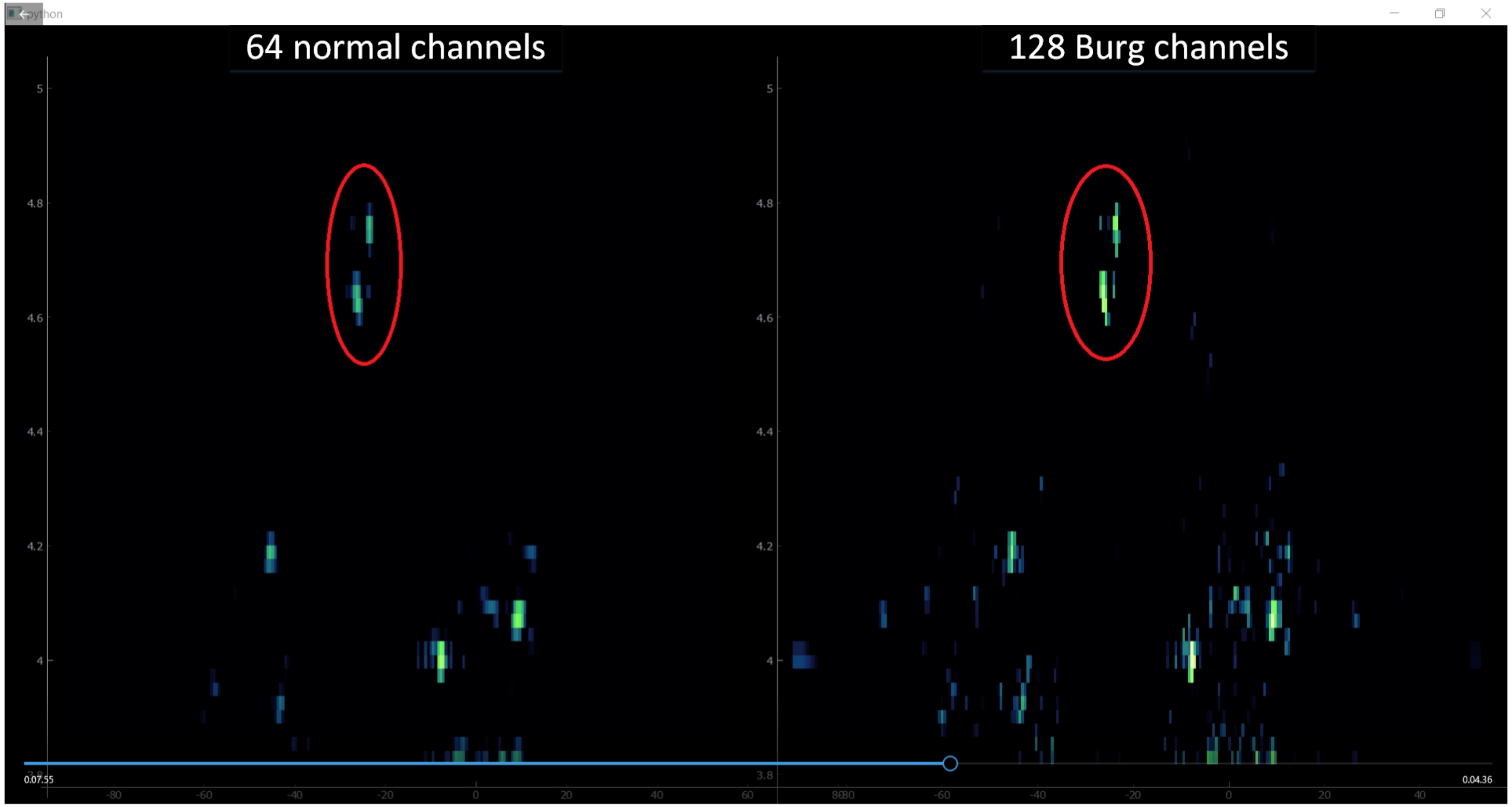
Experimental results: stationary targets

- The performance of the fast Burg algorithm was verified utilizing the radar developed at VTT
- The fast Burg algorithm was able to separate the same closely spaced targets with *M* virtual channels as the dense ULA MIMO radar with *2M* channels.

Measurement cases	15 MIMO virtual channels	29 MIMO virtual channels	15 virtual + 14 Burg MIMO channels
Two metallic poles 8° apart from each other. Range 1.5 m			
Three humans were standing close to each other Range: 7 m			

Experimental results: Walking person detection

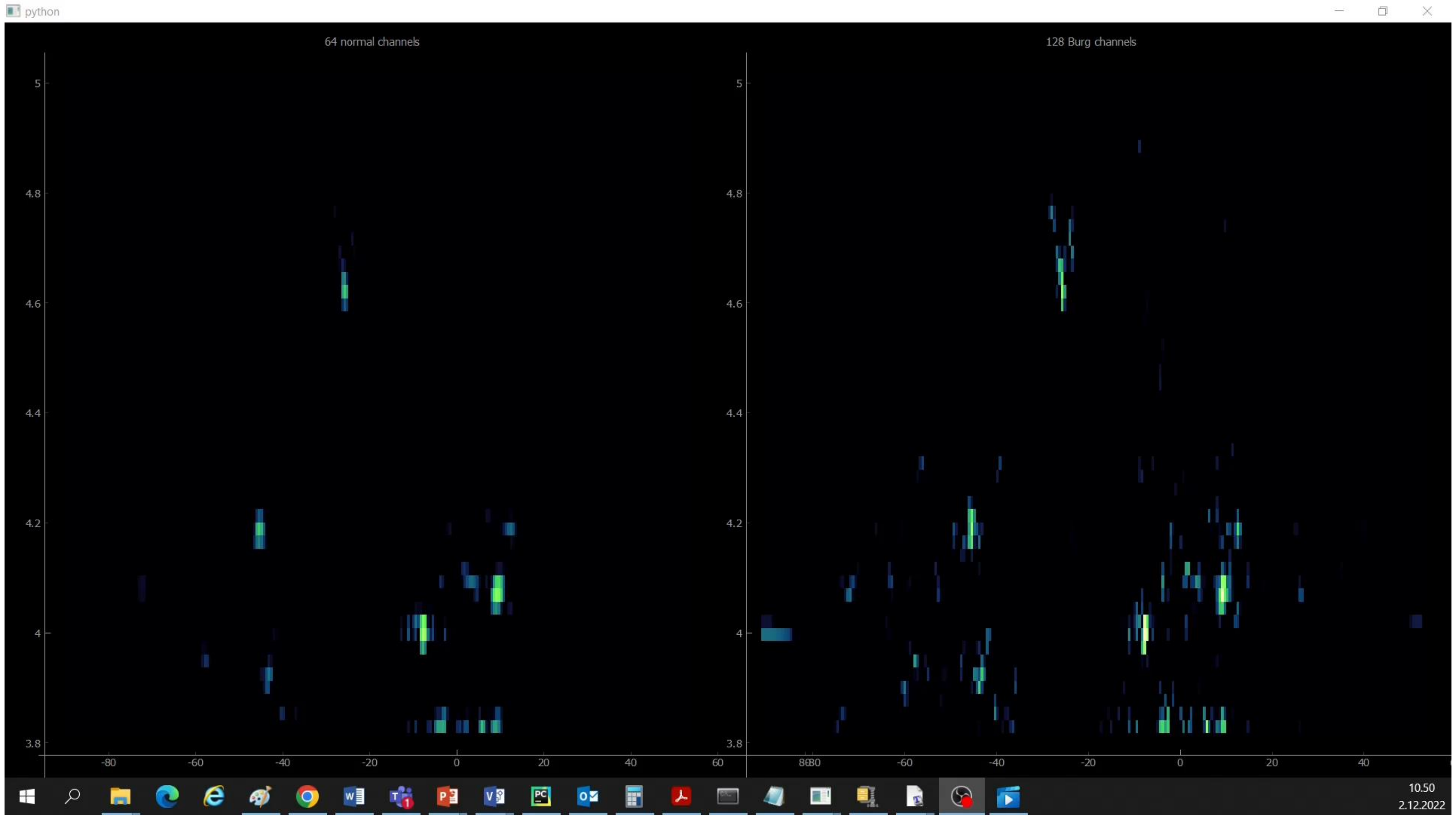
- If we use Burg from the Python library:
  - fps = 2, p = 48.
- Fast Burg:
  - fps = 29, p = 48.
- The Fast Burg is 14.5 times faster than the conventional Burg method. almost double the radar angular resolution.



Experimental results: Walking person detection

- These differences between figures with moving targets are not so clearly as in simulator results and stationary target cases.
- However, we can see that this fast Burg algorithm also works in real time measurements.

64 normal channels	128 Burg channels



Summary

- In this presentation, a fast super-resolution Burg algorithm for increasing the radar angular resolution is presented.
- The fast Burg algorithm was able to separate the same closely spaced targets with *M* virtual channels as the dense ULA MIMO radar with 2*M* channels.
  - Thus, the Burg algorithm can almost double the radar angular resolution.
- The proposed algorithm is 14.5 times faster than the conventional Burg method.
- The algorithm is validated with simulation results as well as experimental measurement results with 60GHz MIMO FMCW radar.
- Fast Burg algorithm shows very promising results in enhancing the spatial resolution of the radar numerically with minimal cost in processing time.