Model And Algorithm Super Resolution For Increase Effectively Digital Antenna Array

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Abstract: The focus of this research paper is to model super resolution algorithm based system for enhanced digital antenna array propagation. In most of these areas, a large effort has been made by researchers and system manufacturers to develop sensors and transmission components that enable super-resolution digital antenna array. However, resolution is inherently limited. The resolution of a digital signal transmission based system characterizes the level of spatial detail at which it captures signals and – besides the contrast resolution – it is considered as a major quality indicator. This is obvious in digital signal transmission, where the super resolution algorithm is directly related to the acquisition of fine textures in a scene. In remote sensing as another prominent example, one is interested in measuring information on a planet surface over long distances, which requires super-resolution algorithm. The focus of this research lies in computational techniques that consider the pixel pitch as the limiting property for digital antenna array. Super resolution method has the objective to reconstruct digital array at finer array sampling from one or an entire sequence of under-sampled array and have been widely investigated in signal processing. This improvement of the array sampling is due to redundancies or complementary information encoded in low-resolution arrays. As the primary goal in this area lies in an enhancement of the digital array sampling, we use the super resolution technique. The research introduces novel multi-channel super-resolution algorithms that are applicable to various digital antenna array setups. The multi-channel super resolution algorithm exploits the existence of a set of modalities in contrast to conventional methods that consider only a single one with an outstanding accuracy of 96.89% for classification of all digital antenna arrays at the clock speed of 100 MHz with the size of each processing element is 10^8 microns on python platform.

Keyword: Super resolution, signals, antenna, array, sampling, multi-channel, frequency, bandwidth.

1. INTRODUCTION

Over the past decades, a variety of super-resolution techniques emerged in different scientific disciplines. Common to all of these approaches is the goal to enhance the super resolution of an imaging system by engineering the resolution restricting aspects discussed in [1]. To the best of our knowledge, there is no clear taxonomy regarding the meaning of super-resolution and the techniques may fundamentally differ. This work distinguishes between instrumental and computational super-resolution.

The instrumental approach, also known as optical super-resolution, is focused on an engineering of the phased DAA in order to increase the band-limitation of the system. Methods that are related to this class have been widely studied in physics and optical engineering and include, among others, the use of photo switchable proteins in microscopy or super lenses as mentioned in [2]. These techniques aim at breaking the diffraction limit as a resolution limiting property. However, it is in the very nature of the instrumental approach that it requires modifications on the underlying hardware, which is beyond the scope of this work.

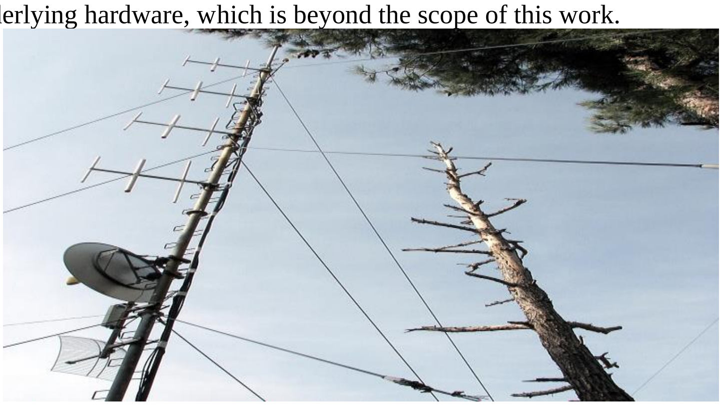

Figure 1: An antenna tower engineered with standard phase digital antenna array with four processing elements [3].

Computational super-resolution is a complementary approach and features resolution enhancement by means of software – without considerable effort regarding hardware modifications. This methodology is well-suited for low- cost imaging or workflows that do not allow changes on the system hardware. This area can be further divided into two domains: diffractive and geometrical approaches as mentioned in [4]. On the one hand, diffractive super-resolution aims at overcoming the diffraction barrier related to the optical system retrospectively. Geometrical super-resolution on the other hand has the goal to circumvent the limitations related to the sensor. One approach is to address the active pixel area as a resolution limiting factor. This has the goal to alleviate the low-pass effect caused by spatial sampling with pixels of finite size. In contrast to these methods, the focus of this paper lies in computational techniques that consider the pixel pitch as the limiting property. These methods have the objective to reconstruct images at finer pixel sampling from one or an entire sequence of under-sampled images and have been widely investigated in signal processing. Under-sampling refers to the fact that raw images are sampled below the Nyquist-Shannon frequency and are therefore affected by aliasing as mentioned in [5]. This improvement of the pixel sampling is due to redundancies or complementary information encoded in low-resolution images. As the primary goal in this area lies in an enhancement of the pixel sampling, we use the pixel resolution as a synonym [21-25]. The sampling of a continuous signal is first modeled for single channels, where one set of discrete samples is obtained from the original signal. For convenience, but without loss of generality, this process is modeled for one-dimensional signals.

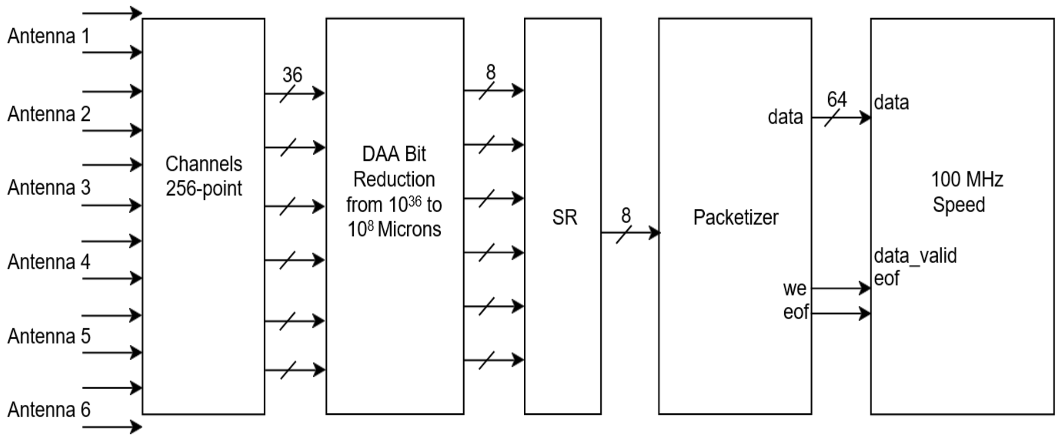

Figure 2: The architecture for increasing the effectiveness of DAA by reducing the number of bits from 36 to 8. The packetizer splits the data into 64 packets with 8 bins in each to reach 100 MHz clock speed to transmit the data to the network switch.

As the different dimensions of multidimensional signals are separable, the underlying theory can be extended and applied to each individual dimension. Since common physical measurements such as digital images are real-valued, we limited the following analysis to real-valued signals.

1.1. Problem Statement

In this context, super-resolution aims at reconstructing a digital signal that is free of aliasing artifacts from an under-sampled signal. This problem is based on the concept of multi-channel sampling, where a continuous array signal is sampled multiple times as opposed to classical single-channel sampling. Super-resolution can be seen as a fusion of multiple channels in order to overcome the limitations stated by the sampling of digital antenna array for a single channel. This is feasible by exploiting complementary information across the channels. In case of digital antenna array, these channels correspond to different frames of array sequence taken from the same scene, whereas each frame contains a complementary view as the problems are further described below:

- How does the digital antenna array signals impact on the modeling of the access strategy to improve the access capability for communication?
- Is the super resolution algorithm supports decision significant for the enhancement of the access decision for digital antenna array at the clock speed of 100 MHz?
- If so, how can the super resolution algorithm be embedded with the access strategy to overcome the communication issues for sensing-throughput trade-off issue in designing?
- What is the best way to design the multi-channel super resolution algorithm sensing mechanism with access strategy for the purpose of overcome the communication issues and throughput trade-off issue in digital antenna array (DAA)?

We will overcome the above-mentioned problems with more advance design of digital antennas using the multi-channel super resolution algorithm.

1.2. Aim of Study

The major contributions of this research paper concern the theory and the development of computational methods for digital antenna array (DAA) using the multi-channel super-resolution algorithm. The contribution concerns the development of super-resolution methods for DAA. For this domain, we introduce novel multi-channel super-resolution algorithms that are applicable to various phased array setups. This algorithm exploits the existence of a set of signaling modalities in contrast to conventional methods that consider only a single one. The goal of the phased array based digital antenna array to create an instrument for more reliable wireless communication in hostile environments. To accomplish this goal, the research aims to build a multichannel, broadband digital array signal processing platform. Implement multi-channel super resolution algorithm for real time beam steering and interference cancellation. Demonstrate the platform and algorithms for improved communications in simulation environment using python programming language.

2. Background

A common theme between the Digital Antenna Arrays and the Adaptive Broadband Beamforming System for Naval Communications is the use of a phased array antenna with digital beamforming. The field of phased arrays and digital beamforming is mature and has material published in [6]. Research cannot give an in depth review of these topics but to give a brief summary and examples from some of the more comprehensive papers.

In 2015, researchers discussed in [7] an overview of the theory and architecture of phased arrays. Phased arrays receive significant interest because of the ability to quickly form multiple beams. This can be accomplished using either passive or active arrays as explained by the authors. The Digital Antenna Arrays and Adaptive Broadband Beamforming System for Wireless Communications use active receiving arrays. Active arrays, though still expensive, are becoming increasingly affordable. With a decrease in the cost of active phased arrays and an increase in available computation power, phased arrays and beamforming can be implemented in more applications.

Researcher in [8] provide a wonderful overview to beamforming, or spatial filtering. They summarize that spatial filtering can separate two signals coming from different directions, even if they have the same frequency content. They point out that spatial filtering (beamforming) is similar to temporal filtering, which filters data from one element collected over a period of time. One such similarity is aliasing. The authors also mention that beamforming can be done on individual frequency channels which they call frequency domain beamforming. This is of interest to the radio astronomy research group because frequency domain beamforming is applied in the Adaptive Broadband Beamforming System for wireless communications as described in [9]. Mention to, and references for, statistically optimal beamformers are given as well as applications that use phased arrays and beamforming.

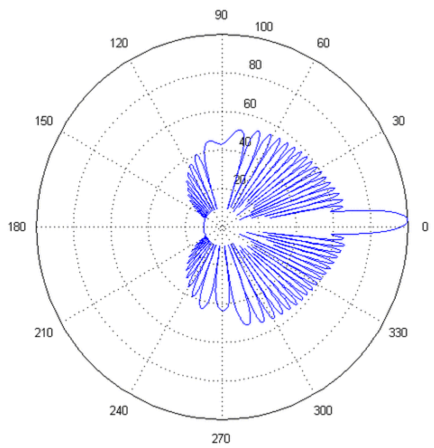

Figure 2: Radiation pattern of phased digital antenna array in oscillation [10].

One application of phased arrays and beamforming is radar. In [11], that there are advantages of using an electronically scanned array (ESA), instead of a rotating dish. One of the main advantages, as explained by researcher in [12], is the update rate of the radar. For a mechanical dish, the update rate is limited by how fast the dish can turn. An ESA is not limited by physical motion because it can form its beams electronically. This allows an ESA to simultaneously track hundreds of targets by changing its beams in fractions of seconds. Another small advantage that a phased array has is it will never have a failed mechanical part.

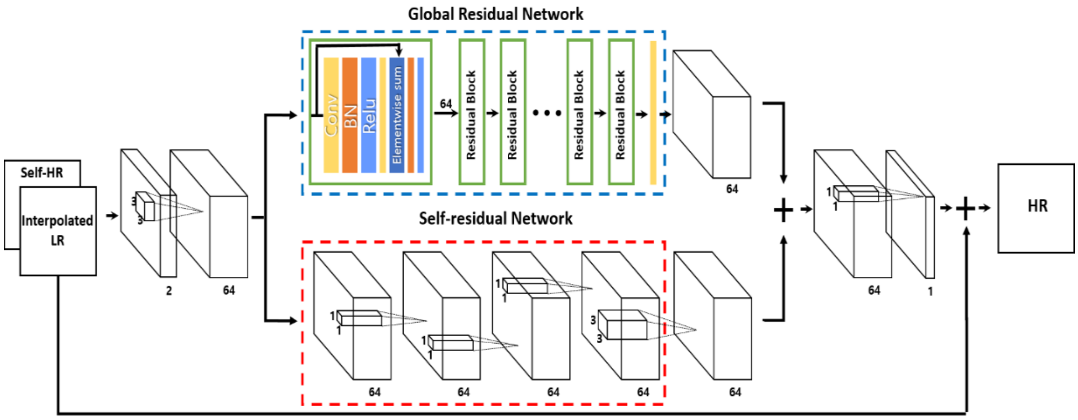

Figure 3: Deep CNN architecture for supper resolution algorithm as a mean of communication with enhanced digital antenna array (DAA) including residual blocks for communication [13].

Another application for phased arrays and beamforming is communications. In [14], researchers present on digital adaptive array that is used in a spread-spectrum communication system. This system used an LMS algorithm to track a desired signal while also nulling interference. Compton also discusses the importance of selecting signal waveforms so that the beamformer weights do not reduce the effectiveness of the communication system. In another paper [15], researchers examine the case where there are numerous interferers in the super resolution algorithm of a communication system. Adaptively weighted beams are used to reduce the time of a link outage if these interferers cross over into the main beam. These papers show that beamforming can be successful when implemented in communication systems in the presence of interference.

2.1. Single Channel Super Resolution Algorithm

The single-channel sampling as theoretical framework for super-resolution. This theory considered ideal sampling as well as real sampling in the presence of a signal kernel. Super-resolution was formulated as linear inverse problem that states the relation between a continuous signal and discrete channels that are captured by sampling the continuous signal multiple times. In this context, super-resolution aims at reconstructing an aliasing-free signal from multiple under-sampled channels as mentioned in [16]. In order to derive fundamental limits of super-resolution, the properties of the underlying inverse problem were analyzed. First, the relationship between super- resolution and the DAA sampling theorem. It was shown that the effective magnification, achievable by super-resolution, is bounded by the band-limitation of the continuous signal as well as the cut-off frequency of the blur kernel in case of real sampling as mentioned in [17]. Second, the uniqueness of super-resolution reconstruction was examined. This analysis shows that super-resolution requires complementary information in multiple channels to provide a unique solution. The necessary and sufficient conditions to gain complementary information involve properties of the channel offsets or the DAA kernel.

2.2. Transposed Block Face-Splitting Product

Early approaches describe super-resolution reconstruction in the frequency domain based on the multi-channel sampling theory presented. In this context, the method employs the Fourier shift theorem to exploit translational subpixel motion in a sequence of low-resolution images. This yields a generative model for super-resolution in the Fourier domain as mentioned in [18]. Translational motion is first determined by means of image registration, which can be performed in the Fourier domain using phase correlation. Then, super-resolution is implemented as inversion of the underlying model equations parametrized by the estimated motion.

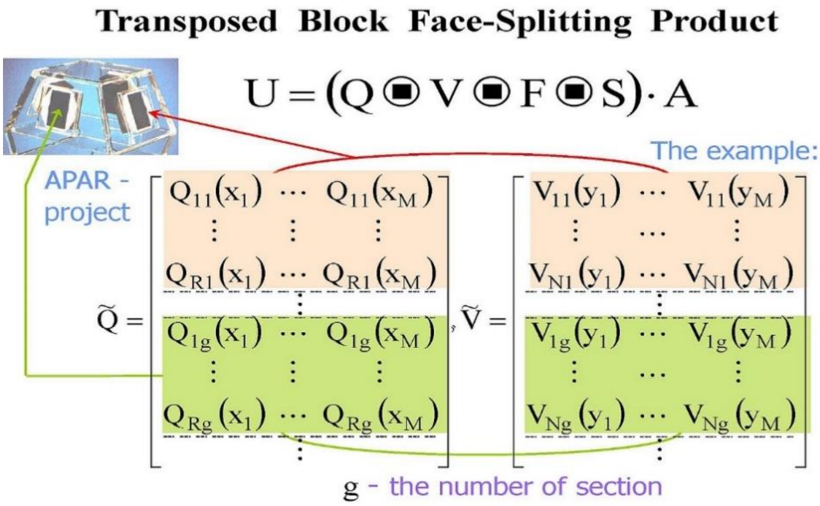

Figure 4: Transposed Block Face-splitting product in the model of a Multi-Face radar with DAA [19].

In the approaches of DAA, this concept has been further extended to tackle sensor noise as well as blurring in the image formation. Researchers in [20] have proposed simultaneous super-resolution and translation estimation in the Fourier domain. In [21], researchers have employed the discrete cosine transform (DCT) for super-resolution as alternative to the Fourier transform. The frequency domain formulation provides valuable theoretical insights to super-resolution and the use of the FFT as a computational tool enables efficient implementations of these algorithms. However, only simple motion models can be used in [22]. For instance, the Fourier shift theorem enables the description of translational motion but cannot model arbitrary displacements. In particular, it is not feasible to handle non-rigid motion. Additionally, blur needs to be described by DAA to be tractable by means of the Fourier transform.

3. Methodology

A digital antenna array is a group of antennas that can electronically steer an antenna beam by applying a phase shift at each element. Another advantage of phased arrays is that adding more elements to the array, creates a more directive beam. These two properties allow the implementation of digital antenna arrays, where rotating dish antennas have been used in the past. The simplest digital antenna array configuration is the medium sized array (MSA), where all the elements are equally spaced. The traditional method to examine a phased array beam pattern is to use the array factor method. This method does not take into effect mutual coupling between elements and may not be accurate enough for high sensitivity applications but is useful in gaining simple intuition. By using the reciprocity theorem, insights gained from transmitting arrays can be applied to receiving arrays.

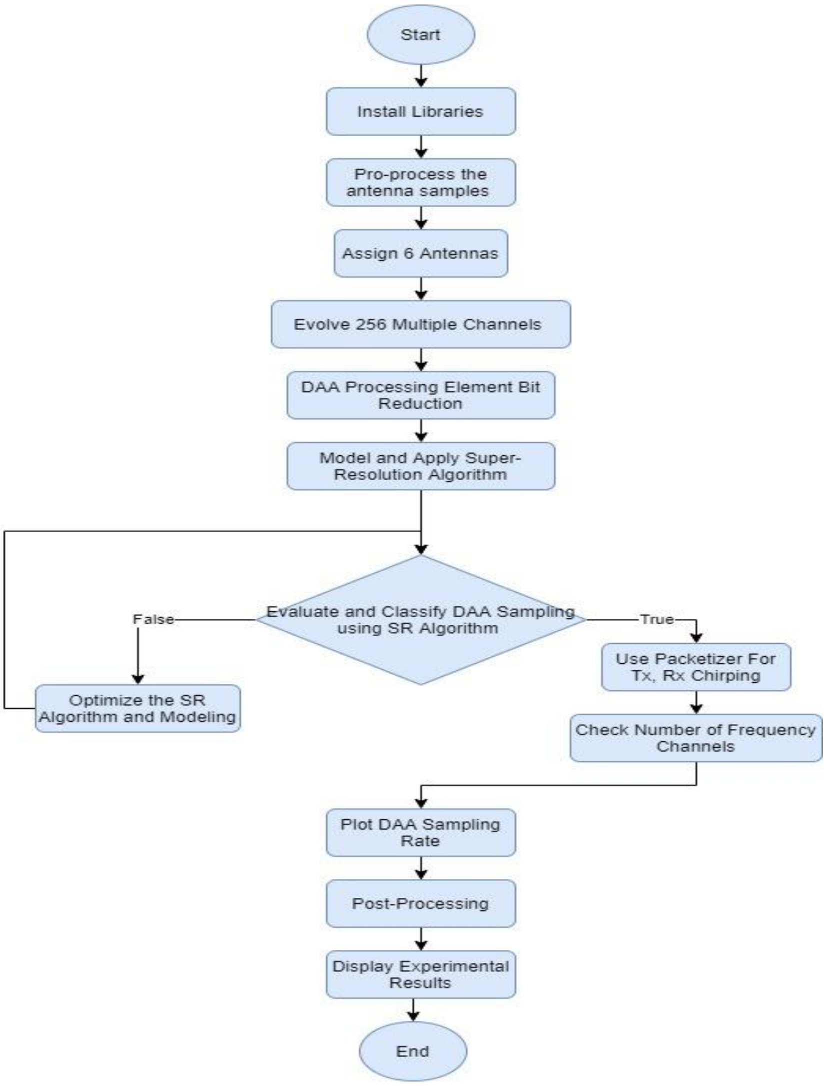

Figure 5: Flow diagram of approach being followed.

3.1. Spatial Domain Multi-Channel Sampling

Spatial domain reconstruction can be seen as a complementary trend in the design of super-resolution algorithms. These methods have the goal to enhance the flexibility regarding the choice of the image formation model. Research proposed interpolation-based reconstruction based on the multi-channel sampling theory that has later been adopted in other spatial domain methods. Such algorithms differ in their implementations but share a similar conceptual structure. Their concept is described by a multi-stage procedure with the following steps:

1. Motion estimation by means of image registration determines the subpixel motion between multiple low-resolution frames.
2. Motion compensation transforms all low-resolution frames into a common high-resolution grid according to the motion estimate.
3. Non-uniform interpolation determines a super-resolved image based on the motion-compensated frames.

Some of the well-known methods in this area include normalized convolution, kernel regression, and adaptive Wiener filtering. More recently, adaptive weighting schemes as well as hybrid multi-frame and single-image reconstruction have been proposed to alleviate the impact of motion estimation inaccuracies. These schemes can also be augmented by signal transformation to remove disruption after the interpolation.

3.2. Multi-Channel Super Resolution Algorithm

In terms of multi-channel super-resolution, the blur kernel related to the digital antenna array (DAA) is assumed to be known, and so are the parameters of the generative super resolution model. This class of algorithms is closely related to multi-channel deconvolution and treats the blur as a latent variable. Multi-channel super-resolution is commonly implemented as an interlacing of non-multi-channel reconstruction and blur estimation in joint optimization frameworks. Super-resolution under an unknown signal received has been investigated. Such methods combine multi-frame resolution enhancement and multi-channel deconvolution to unified frameworks. These are formulated via iterative spatial domain reconstruction with known subpixel motion. \

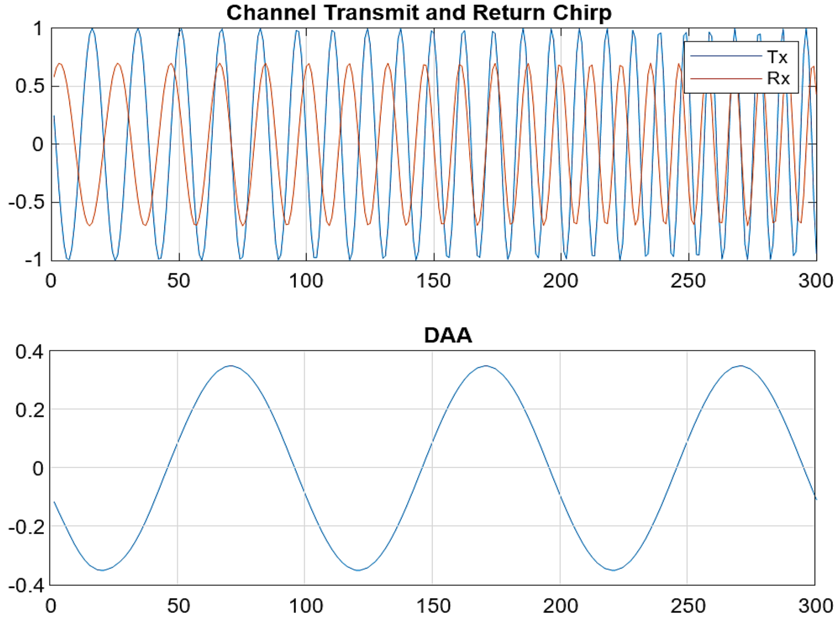

Figure 6: Tx, Rx and resulting DAA. Top: Multi-channel chirp is transmitted and the returned signal is a delayed and attenuated chirp. When the transmitted signal is used to mix down the received chirp, a single frequency is the result (Bottom). The intermediate frequency depends on the time delay and corresponds to the targets range.

This research has proposed to treat disruption, subpixel motion and the latent high-resolution image as triple coupled variables to determine them simultaneously. This circumvents a direct motion estimation on low-resolution frames. More recently, the handling of motion blur has been studied for situations where optical and sensor blur are no appropriate models, e. g. fast antenna-shake. As another technique in the field of multi-channel super resolution statistics, variation inference has proven to be a valuable tool. As opposed to the T_x and R_x schemes that provide point estimates, variation inference aims at deter- mining full posterior probability distributions. This enables a joint estimation of the super-resolved image along with latent model parameters.

3.3. Digital Antenna Array Sampling

In addition to motion estimation, the uncertainties of parameters employed in the DAA signal formation/sampling model have a considerable impact on super-resolution. Compared to conditions in many real-world signaling setups, super-resolution usually approximates the true physics of image acquisition with simplified mathematical models. One aspect that is rarely considered is internal processing of image data in the camera system, e. g. signal compression or white-balancing. Another issue is measurement noise that does not follow a simple space invariant normal distribution, e. g. due to invalid pixels related to impulse noise or mixed noise. The influence of these aspects is demonstrated by corrupting low-resolution data by salt-and-pepper noise using a fraction of 0.5 % invalid pixels as depicted. Super-resolution on the corrupted low-resolution frames is not able to compensate for valid transmission with the size of each processing element is 10^8 microns.

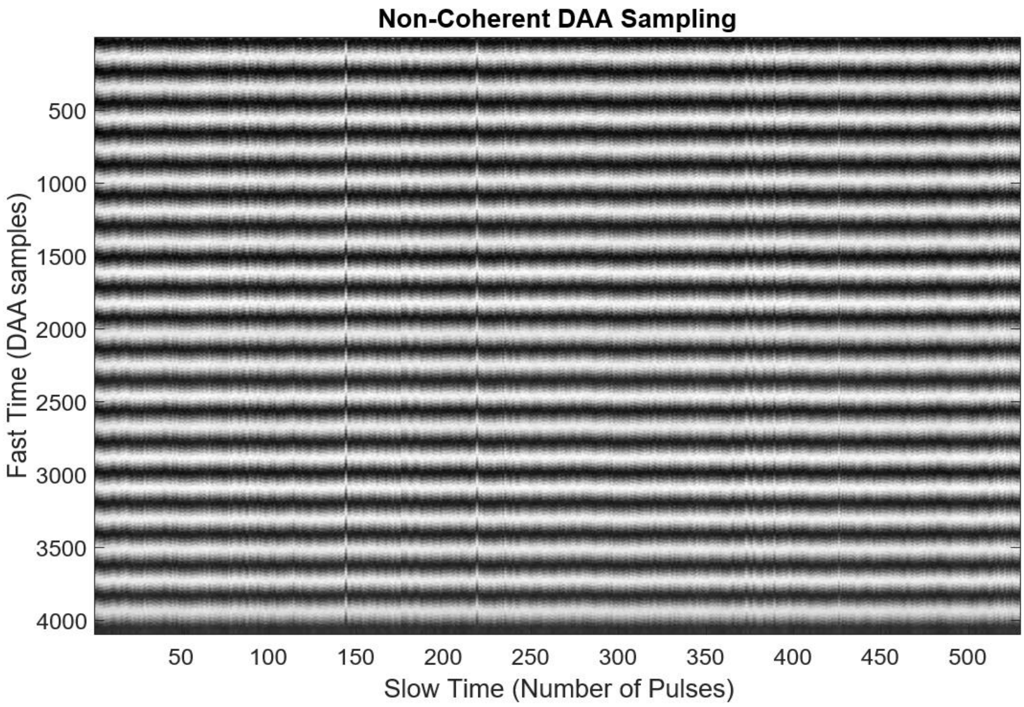

Figure 7: Non-coherent data collected by the multi-channel SR algorithm. For coherent data, each DAA sample on consecutive pules should be the same as the previous pulse. In this figure the DAA samples show jitter, suggesting an incorrect sample offset.

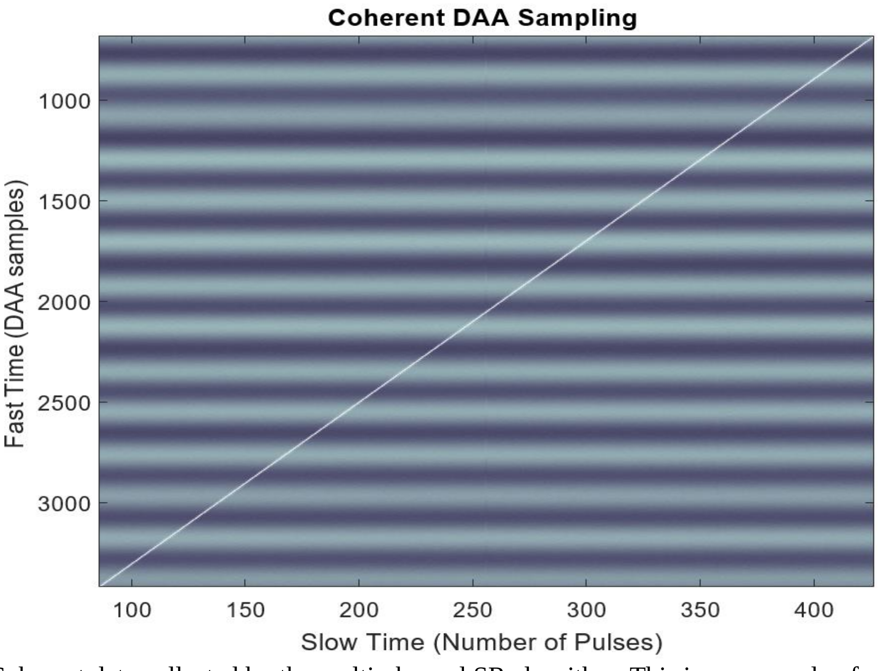

Figure 8: Coherent data collected by the multi-channel SR algorithm. This is an example of coherent data because the DAA values are consistent across multiple pulses.

Besides model parameters, there are also optimization parameters related to the formulation of super-resolution as energy minimization problem. One example are regularization weights that are selected prior to optimization. This is cumbersome as parameter selection is often performed off-line by trial-and-error or by automatic parameter selection schemes. However, in both cases super- resolution is affected by an inappropriate selection and cannot compensate for the uncertainty of the parameters.

4. RESULTS

Understanding the concepts presented in this section provides experimental results that are used throughout the remainder of this paper. By understanding the basics of an DAA with multi-channel super resolution algorithm, an accurate signal model can be developed and algorithms that fit that model can be applied. A knowledge of digital antenna arrays and phased array provides a framework for the Adaptive Broadband Beamforming System for Communications. Finally, familiarity with detection and estimation results helps analyze and implement effective multi-channel super resolution algorithms.

Clock Speed	100 MHz
Total Bandwidth	250 MHz
Range Resolution	0.38 m
Pulse Period	2.048 ms
DAA Sample Rate	0-2 MHz
Unambiguous Range	0.27 m
Transmit Power	30 mW

Table 1: Simulation parameters for the multi-channel super resolution algorithm for sampling of digital antennas with holding on python platform.

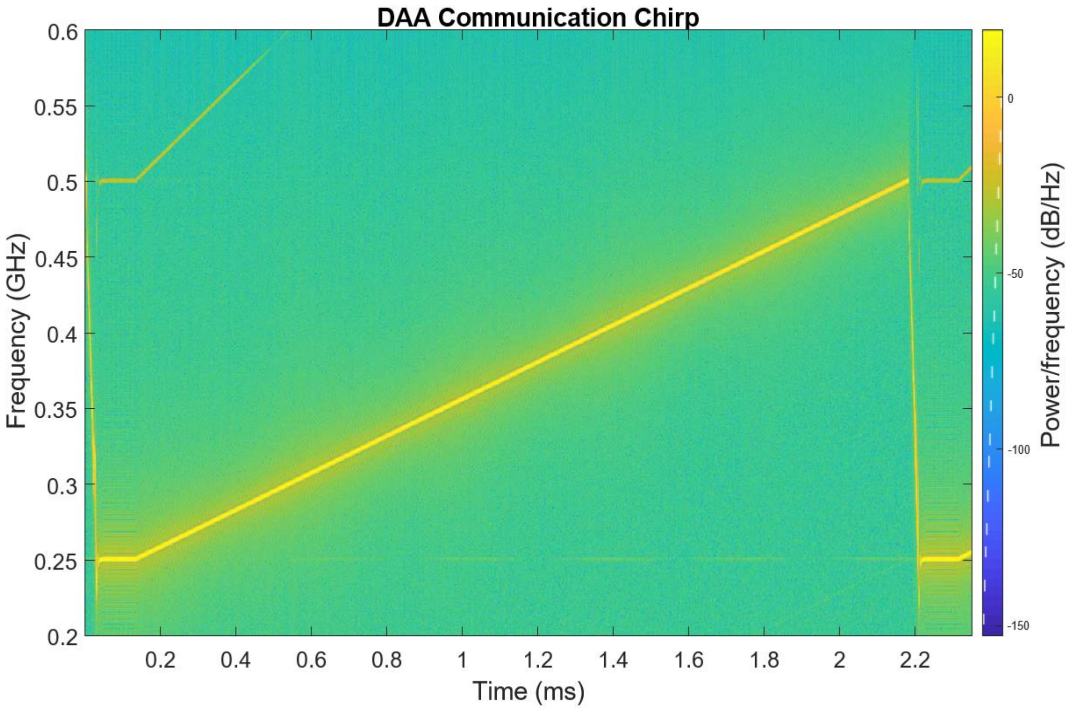

Figure 9: DAA communication chirp from 10-10.25 GHz. This is a sampled spectrogram of the chirp after it is mixed down with a 9.75 GHz local oscillator. The doubled frequency from the mixer is faintly visible.

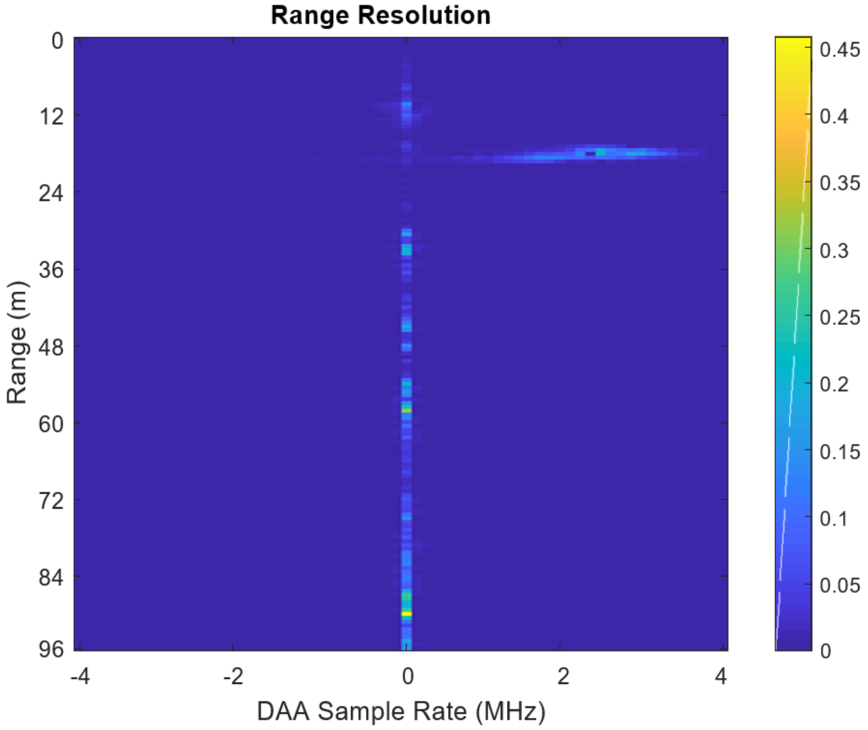

Figure 10: Range Resolution plot of a moving target in an environment with SR algorithm. The DAA sampling rate returns are seen in the 0 MHz frequency bin because it is relatively stationary. A moving target is visible on the right at resolution range of 0.38m.

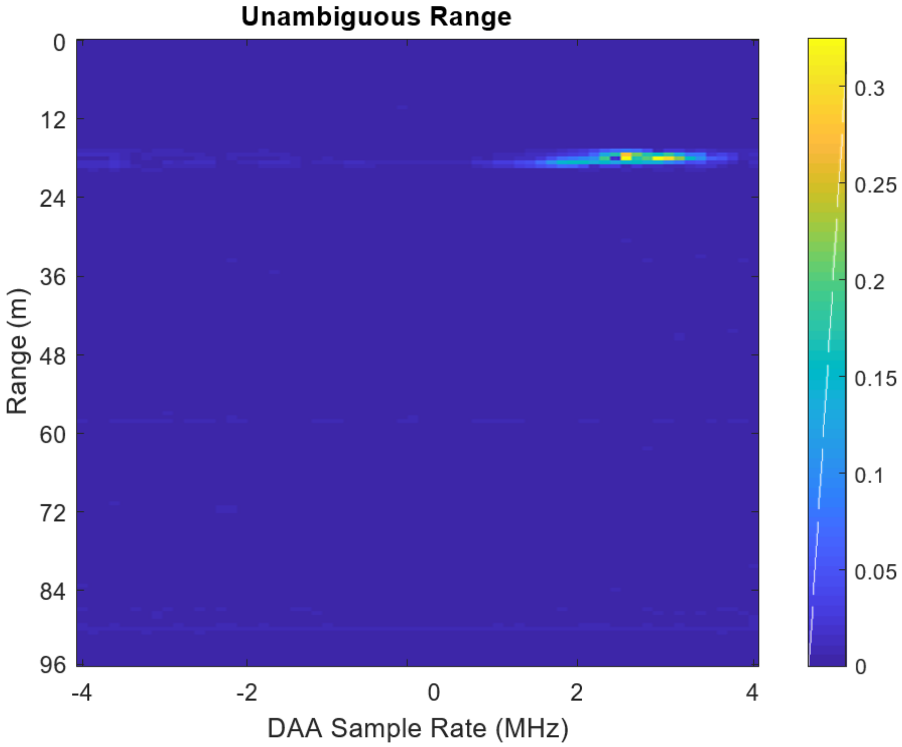

Figure 11: Unambiguous Range plot of a moving target in an environment with SR algorithm. The DAA sampling rate does not return any frequency bin because it is relatively moving. A moving target is visible on the right at unambiguous range of 0.27m.

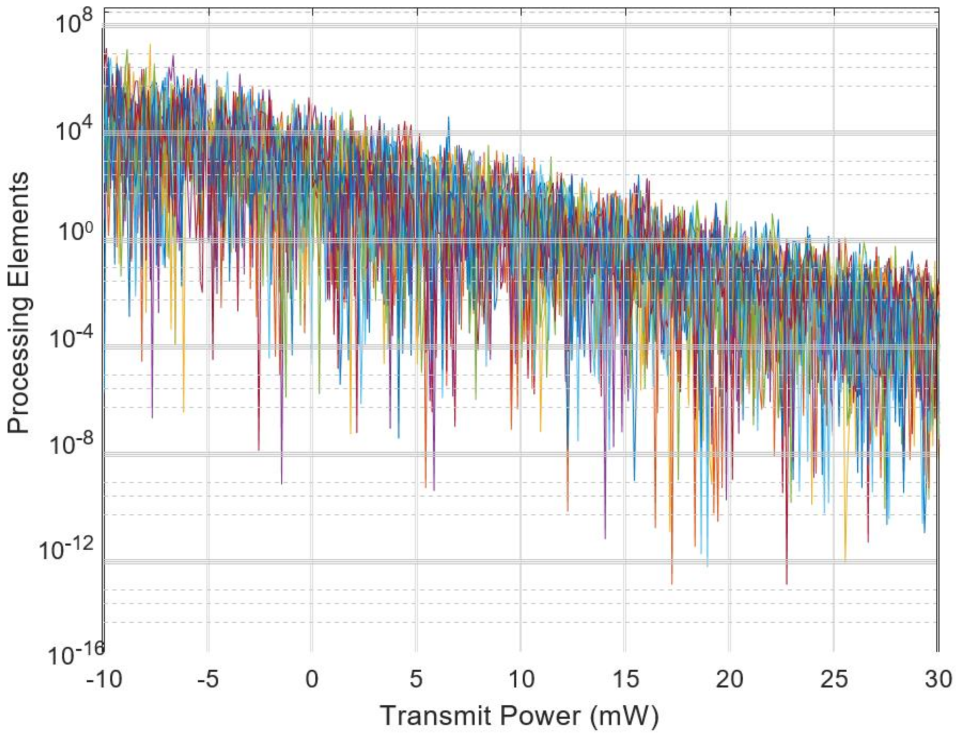

Figure 12: The maximum processing elements rate at 10^8 microns' vs maximum transmit power at 30 mW. Increased transmit power results in decreased processing rate for DAA phase communication and effectiveness.

After the algorithm is applied, DAA correlation, and coherent averaging has been computed by the multi-channel super resolution algorithm, the data is transported to the CPU/GPU where the signal processing algorithms can be applied. The DAA signal processing areas that are addressed in this section include: angle of arrival estimation, estimation of the number of targets, and target detection. There is also a section on some added functionality that is useful for when multiple DAA stations are networked together.

5. Discussion

The final demonstration of this research work consists of an antenna array receives a wide-band communication signal coming from some angle while simultaneously receiving interference coming from a different angle. The data is sampled, split up into narrowband sub channels, beam- forming is applied to remove interference, then the signal is reconstructed and demodulated. Up to this point in the research we can: sample signals, put 96.86% accuracy with multi-channel super resolution algorithm on windows into packets with 10^8 microns processing elements for DAA sampling, capture the data with DAA, apply beamforming, and write the result to a file. To test the system with the beam-former, two different weights were generated. The first beam's weights were set as all ones to maximize the power of a signal arriving at 0 degrees

.

Configuration	High BW	Medium Size Array	Large Array
Number of antennas	18	6	36
Beamforming bandwidth	300 MHz	250 MHz	75 MHz
Total Sampling Rate	800 MHz	400 MHz	200 MHz
Number of frequency channels	768	96	192

Table 2: Different configurations for the digital antenna array. The focus of this research work was on the medium digital sized array.

After beamforming is performed on the selected frequency channels, it is desired to recover the transmitted data. In order for this to happen, the signal must be reconstructed from the output of the multi-channel super resolution algorithm, then it must be demodulated. The DAA is responsible for the reconstruction and demodulation of the signal

.

6. Conclusion

The next several years will see a large increase in smart digital antenna array. The DAA systems that can detect and track multiple signals will be invaluable in the testing and development of effective sense and avoid algorithms. This will further enable the development of UAS technology. Implementation of multi-channel super resolution algorithm allows for faster DAA estimation. This is useful for medium antenna arrays, because it does not require a sweep across all angles. Computing the DAA estimate faster provides more time for other types of processing to take place. Implementation of the multi-channel super resolution algorithm could prove invaluable when there are multiple targets. This algorithm is capable of detecting multiple targets in the same range bin and estimating their DAA. Finally, implementing processing elements for DAA stands at as low as 10^8 microns is exciting in terms of simulation, because it is capable of clutter reduction and detecting moving targets. Post processing on actual DAA data has shown that this can be a successful technique in signal processing. The digital antenna array system for communications has successfully implemented with a digital beamforming backend. This includes sampling signals with an accuracy of 96.89% and taking the DAA data. The architecture for increasing the effectiveness of DAA by reducing the number of bits from 36 to 8. The packetizer splits the data into 64 packets with 8 bins in each to reach 100 MHz clock speed to transmit the data to the network switch.

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