PHASED ARRAY RADAR APPLICATIONS IN AGRICULTURE

Seeing through dust

Rhett Schildroth, Mach, Ely Iowa

OVERVIEW ABSTRACT

This white paper explores the fundamental differences between phased array radar designs and conventional radar sensors, highlighting their advantages over camera vision and LiDAR. This paper aims to explain these advantages, and highlight the potential applications of phased array radar in agriculture, with a specific focus on soil tillage quality, fruit size, density-based yield, advanced height control, estimation and vine cordon detection.

BACKGROUND OF MACH

Before delving into the intricacies of phased array radar technology, it's essential to understand the context in which Mach, the driving force behind this technological advancement, operates. With a rich history spanning over two decades, Mach has been at the forefront of agricultural technology innovations rooted in a commitment to revolutionize automation for Original Equipment Manufacturers (OEMs). Learn more about Mach at www.mach.io

Importance to OEMs: Transforming Agricultural Practices

As the agricultural landscape undergoes a paradigm shift towards automation, the role of OEMs becomes increasingly vital. Mach's focus on delivering advanced automation technology directly addresses these evolving needs of OEMs, providing them with the tools to drive efficiency, precision, and sustainability in a wide variety of farming applications.

As Mach began on various OEM solutions, a need was recognized for a more advanced sensing solution. While implementing LiDARs Cameras, and traditional radar with customers the limitations of each sensor were clear. In general, OEMs had to make significant trade offs which involved sacrificing the resolution of LiDARs and cameras for radars in limited visibility conditions that included dust, rain or fog. Therefore the need for a higher resolution non-optical solution became apparent making phased array radar technology a clear path forward.

Phased array radar technology has played a critical role in various industries, including aerospace, defense, and meteorology. In recent years, there has been growing interest in applying radar technology in agriculture to enhance farming practices and increase crop yields. Most recently with the advent of unmanned machinery, the need for improved sensing technology in farming has become even more pressing. Phased array radar technology offers unique capabilities and significant advantages over conventional radar sensors, camera vision, and LiDAR.

A phased array radar technology leverages an assembly of individual antenna elements. Each antenna element within the array can be independently controlled, allowing for meticulous adjustments in the phase of emitted signals. This capability enables the fine-tuning of the radar's ovWerall beam direction and characteristics, facilitating detailed observations of soil structure, vegetation, crops and other items of interest. By utilizing longer waveform frequencies and manipulating the radar beam, phased array radar systems can penetrate vegetation and provide high resolution returns, generating critical data on soil tillage effectiveness and optimizing yield estimations. This advanced radar technology thus holds the potential to significantly enhance automated decision-making processes in precision agriculture. For example the data may allow automatic adjustment of tillage depth and angle to target an optimal amount of residue coverage or provide a forecast measurement of crop mass to enter a harvester. Furthermore, due to the penetrating properties of the radar signal, it may be possible to detect obfuscated debris in tall grass or limited visibility environments.

PHASED ARRAY RADAR VERSUS CONVENTIONAL RADAR, CAMERA VISION, LIDAR, AND OTHER HIGH RESOLUTION RADARS

Before further exploring the applications of phased array radar, it is crucial to comprehend the technologies it seeks to surpass. There are many sensors available in the marketplace today including LiDAR, or light detection and ranging, camera vision, conventional radar, and a myriad of other high resolution radars. These various sensors have been stalwarts in various industries, including agriculture. However, the limitations of these technologies become evident when compared to the precision and adaptability offered by phased array radar technology.

In the following sections, this paper will delve deeper into the advantages of phased array radar in agricultural applications, with a spotlight on soil characteristics monitoring, soil tillage work quality assessment, crop mass measurements, and vine cordon detection; in comparison to other applications available. As agriculture embraces the dawn of automation, understanding and harnessing these technologies becomes crucial for driving sustainable and efficient farming practices.

Mach's Phased Array Radar, RadX

RadX, Mach's patent pending phased array radar product, employs an array of individually controlled antenna elements. By adjusting the phase and amplitude of the signals emitted by each antenna element, the radar beam's direction and characteristics can be precisely controlled. Key features of RadX include:

Beam Steering:

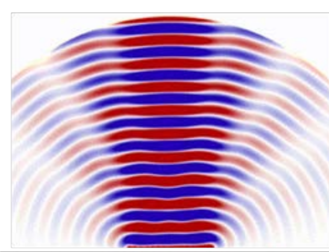
The core advantage of using phased array radar technology to achieve high-quality data, lies in its beam steering capability. This capability allows for the electronic control of the radar beam without necessitating physical or mechanical movement of the antenna array. This is accomplished through precise adjustments in the relative phase of signals emitted by each antenna element. Such capability not only enables swift redirection of the beam to focus on specific areas of interest, but also significantly enhances the radar's ability to isolate the signal from background noise, thereby improving the signal-to-noise ratio (SNR) in the collected data. The ability to quickly adjust beam direction ensures that the radar can concentrate its sensing power on the most relevant targets or areas, optimizing data quality and reliability. This is particularly important in environments with high levels of ambient noise, or where targets are small or located at varying distances.

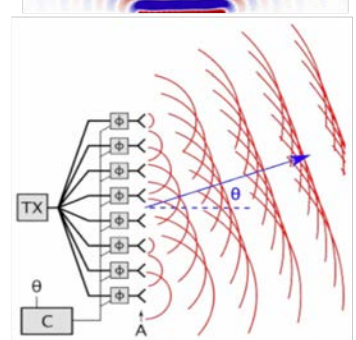
Improved Resolution and Accuracy:

By controlling the amplitude and phase of the signals from each antenna element, phased array systems, such as RadX, can focus the beam more narrowly than conventional radars. This fine control over the beam shape results in better spatial resolution, and allows for more accurate determination of target size, shape, and features. The improved resolution is critical for identifying and distinguishing between multiple closely spaced objects, which is vital in cluttered environments.

Adaptive Beamforming:

Advanced signal processing techniques can be applied to the data collected by phased array systems, enabling adaptive beamforming. This process involves dynamically adjusting the beam shape and direction to optimize performance, such as enhancing SNR. Adaptive beamforming improves the operational effectiveness of the radar in challenging conditions.





Scalability and Modular Design:

Phased array radar systems are inherently scalable, meaning their performance can be enhanced by simply increasing the number of antenna elements. This modular design approach allows for the tailored configuration of radar systems to meet specific operational requirements, providing flexibility across a wide range of applications and platforms.

RadX Advantages Over Camera Vision

Phased array radar stands out as a superior choice for OEMs in the agricultural sector when compared to camera vision, thanks to a myriad of advantages:

Non-Dependence on Lighting:

Phased array radar operates independently of ambient lighting conditions, making it suitable for use in low-light or nighttime environments. Unlike camera vision, which relies heavily on adequate lighting for optimal performance, phased array radar operates seamlessly in low-light or nighttime environments. This capability broadens the operational scope of agricultural machinery, allowing for uninterrupted functionality regardless of the time of day or weather conditions.

Unaffected by Dust and Fog:

Radar waves are less affected by dust, fog, and other atmospheric conditions than optical sensors, ensuring reliable data collection even in adverse weather. This resilience is of paramount importance in the unpredictable and dynamic conditions often encountered in agricultural settings, providing OEMs with a robust solution that performs consistently in the face of challenging weather scenarios.

Improved Range Determination:

Radar data is inherently three-dimensional, reducing the need for complex image processing to extract meaningful depth/range information. This streamlined approach not only simplifies the data interpretation process but also enhances the overall efficiency of agricultural machinery. OEMs can leverage this innate capability to develop precision farming equipment that requires less computational overhead, resulting in faster and more accurate decision-making in the field.

Advantages Over LiDAR

Similar to camera vision, phased array radar products have distinct advantages over LiDAR technology. Here are some of the key differences Mach has discovered:

Cost-Effectiveness:

Phased array radar systems, such as RadX, are often more cost-effective to deploy and maintain compared to LiDAR, making them accessible to a wider range of agricultural applications.

Unaffected by Dust and Fog:

Radar waves are less affected by dust, fog, and other atmospheric conditions than optical sensors, ensuring reliable data collection even in adverse weather.

Reduced Hardware Complexity:

Unlike LiDAR, which often relies on mechanical components such as rotating scanners, RadX eliminates the need for moving parts. The absence of intricate

mechanical components translates into a more robust and durable solution, aligning with the efficiency and longevity demands of agricultural machinery employed by OEMs.

Advantages Over Other Imaging Radars

Lastly, phased array radar technology provides several advantages over other high-resolution radar systems, including:

Increased Signal Penetration:

Many high-resolution imaging radars are designed for automotive purposes, operating within a frequency band of 76 to 81 GHz. This frequency range offers optimal performance for detailed sensing tasks with minimal environmental interference. However, signals in this band have limited range compared to lower frequency bands. Typically, lower frequency bands sacrifice resolution, but by employing phased array technology, RadX can enhance resolution while operating at lower frequencies within and below the X-band. This approach improves signal resilience through vegetation and environmental interference without significantly sacrificing resolution.

Flexibility in Beam Steering:

Unlike fixed-beam radars, phased array systems offer electronic beam steering, which allows for rapid repositioning of the radar beam to focus on different areas of interest without the need for mechanical movement. This rapid “sweeping” of an area enhances the ability to monitor and analyze agricultural fields from various angles and positions, enabling more precise and comprehensive data collection.

High Resolution and Accuracy:

Unlike fixed-beam radars, phased array systems offer electronic beam steering, which allows for rapid repositioning of the radar beam to focus on different areas of interest without the need for mechanical movement. This rapid “sweeping” of an area enhances the ability to monitor and analyze agricultural fields from various angles and positions, enabling more precise and comprehensive data collection.

APPLICATIONS IN AGRICULTURE

Phased Array radar systems provide a variety of different uses in agriculture. After many years of research and testing, Mach determined that the sectors of agriculture that will benefit most from this type of technology include: Tillage, harvesting, mowing, viticulture and vineyard management.

Phased array radar technology holds great potential for improving various agricultural practices in four very specific ways:

> **Soil Tillage Work Quality Assessments**
>
> **Fruit Size and Crop Density-Based Yield Estimations**
>
> **Vine Cordon Detection**
>
> **Seeing Through Vegetation**

The following sections will discuss each of these practices more in-depth.

Soil Tillage Work Quality Assessment

Phased array radar can assess the quality of soil tillage work, ensuring fields are properly prepared for planting. It can detect variations in soil structure and compaction, enabling farmers to make necessary adjustments for optimal crop growth. By seeing through crop residue and canopy, phased array radars can assess soil tillage quality more accurately. This assessment ensures that fields are prepared optimally for planting, contributing to better crop yields and soil health.

As an example, the variation in distance from the measuring sensor to a tilled soil surface was measured at a 1 cm resolution over a square area of 20 cm x 20 cm. The distance variation is shown in Figure 1.

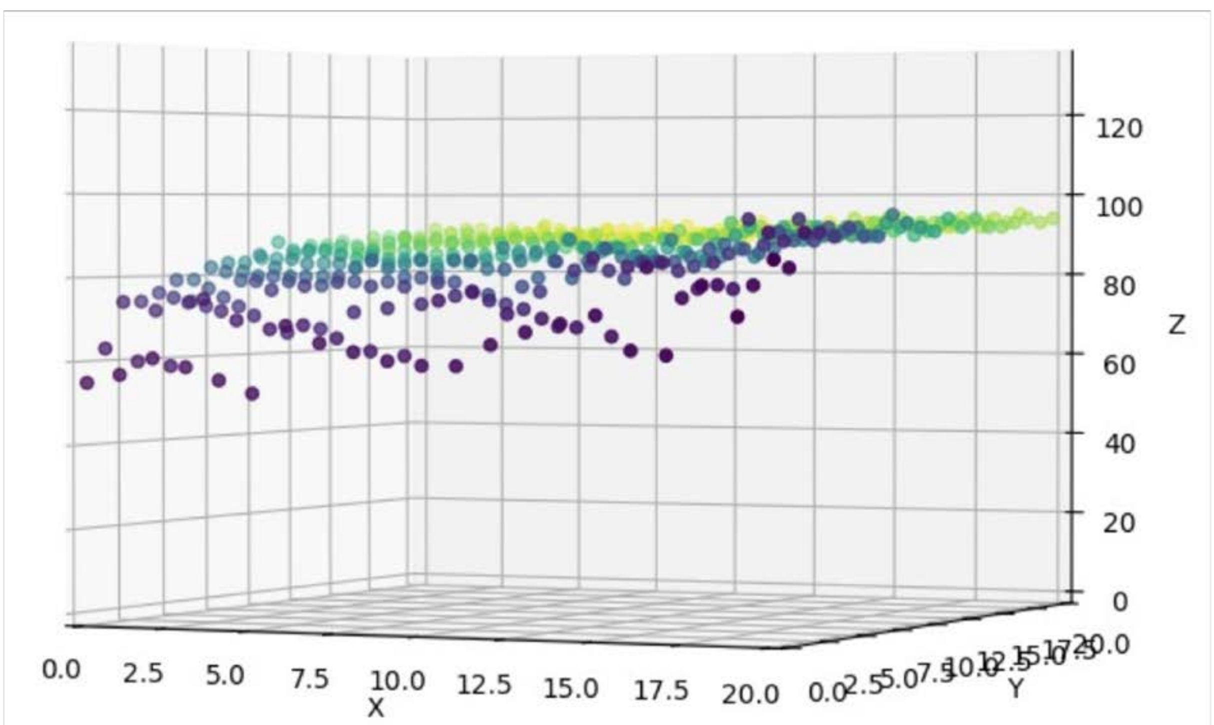


Figure 1: Variation in range measurement used to determine surface roughness.

In addition to measuring the quality of work, a phased array can allow for better tool height measurements by filtering lower energy returns from crop stubble or residue to more accurately assess the height above the soil surface. Traditional radars for height measurement normally only return a single signal thus making it very difficult to filter false readings that can be created by vegetation on the ground.

Fruit Size and Crop Density-Based Yield Estimation

By assessing the amount of energy in returned signals, phased array technology allows for calculations of mass and density. This can be particularly helpful when trying to estimate the amount of yield a crop might produce prior to maturity. It can also be useful as a look ahead for machines processing large quantities of crops like combine harvesters. For example if a harvester can proactively adjust its speed up or down based on the amount of crop it is expected to process within the next meter, it can lead to better efficiency and less yield loss.

Vine Cordon Detection

In vineyards, phased array radar can identify and locate vine cordons, the primary structural component of grapevines. This information is then used in the automation of mechanical components operating on the vines, such as pruners or shoot thinners.

Seeing Through Vegetation

Phased array radar systems possess a unique capability that sets them apart in agricultural applications - the ability to penetrate vegetation cover and provide detailed insights into what lies beneath. An example of this application could include seeing through vines in vineyards to see the size of grape clusters hidden behind canes and leaves or seeing through standing crops and grass to understand what lies ahead.

The key to the phased array radar's ability to see through vegetation lies in the nature of the radar signals themselves. Radar systems use radio waves to detect objects, and the frequency of these waves determines their penetrative capability. Phased array radars can be designed to operate at frequencies that are particularly adept at penetrating vegetation without significant attenuation or scattering of the signal. Lower frequencies, for instance, can travel through leaves, branches, and other organic materials more effectively than higher frequencies, which tend to be absorbed or reflected by the vegetation.

CONCLUSION: NURTURING GROWTH WITH RADX

Agriculture is once again in front of another revolutionary change as automation sits at the forefront of many farmers' and OEM's minds.The technological advancements in phased array radar systems represent a significant leap forward in agricultural monitoring and management. As this paper has discussed, there are a variety of distinct advantages to using phased array radar over conventional options currently on the market.

> ***The resilience of phased array radar to adverse environmental conditions, effortlessly seeing through dust and fog***
>
> ***The ability to "see" through vegetation to ensure reliable data is collected***
>
> ***The opportunity to eliminate the need for complex and cumbersome mechanical components***
>
> ***Most importantly, the cost effectiveness of these applications***

These systems offer a powerful tool for improving the accuracy of crop assessments, enhancing soil management practices, and ultimately allowing for further automation in farming.

While the specific use cases are still yet to be fully realized, the technology shows great promise for farmers and OEM's alike.

In summary, the advantages of phased array radar can be a technologically superior choice for OEMs serving the agricultural industry. Based on Mach's extensive knowledge and history in the space, the work is not done yet. Further research and development in this field are essential to unlock the full potential of phased array radar technology in agriculture.

To find out more information, support the development of phased array technology, or join a mailing list for product updates, please contact radx@mach.io.