Hexray

Ground-Penetrating Imaging Radar

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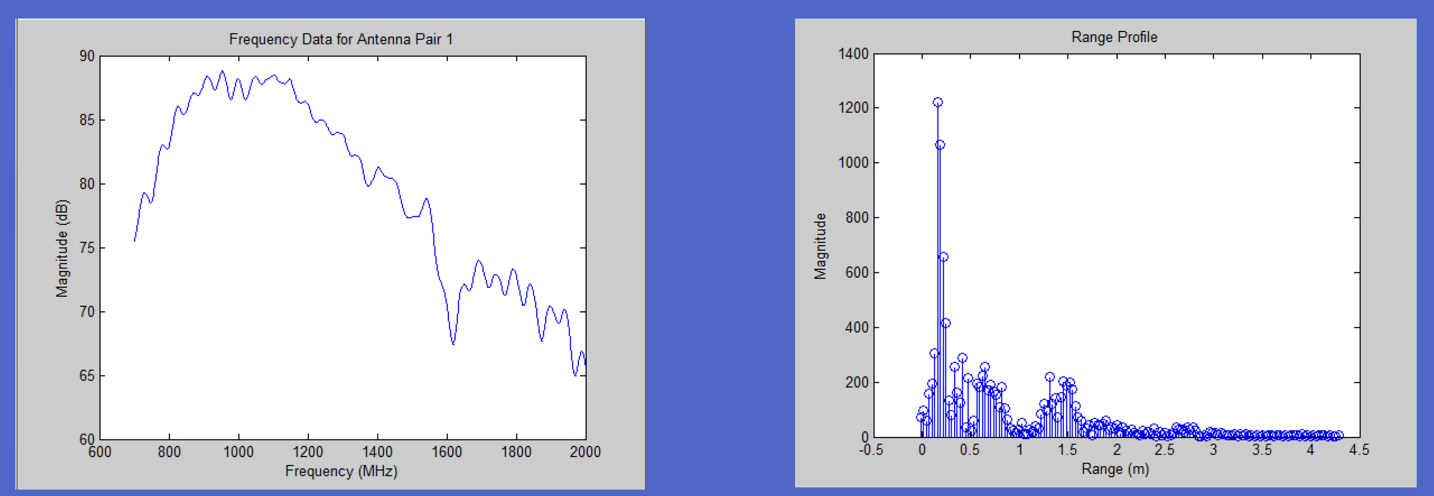
Special thanks to:
Prof. Hua Lee, Dr. Ilan Ben-Yaacov, Vincent Radzicki, and Akela inc.

Introduction to Ground Penetrating Radar

Radar systems detect the position of objects within its range by transmitting electromagnetic radiation in the microwave band to measure the magnitude and delay of reflections from the target. While above-ground radar typically uses a pulsed waveform, continuous wave transmission is required to penetrate a solid substrate. The periodic nature of a continuous wave makes it difficult to discern the delay of a reflection, so the transmitter needs to step through different frequencies to calculation of the range via an inverse Fourier transform.



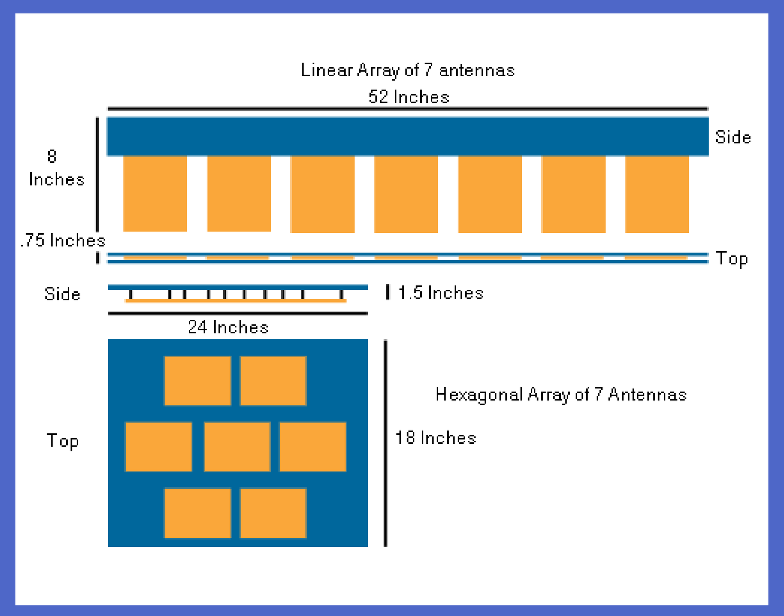
The image on the left is an example of frequency data collected with our system. The left image depicts the range data that we calculate with an inverse Fourier transform. The large peak is due to the signal traveling directly between antennas without reflecting off the target. The smaller peaks near 0.5 meters are the desired signal.

Introduction to Synthetic Aperture Radar (SAR)

A single pair of radar antennas can only determine the distance of a target, and not the direction that it lies in. Imaging radar systems use multiple transmit-receive pairs at known locations to triangulate a target's position. Additionally, the array of antennas can be moved to collect data from different perspectives in order to increase image size and resolution.

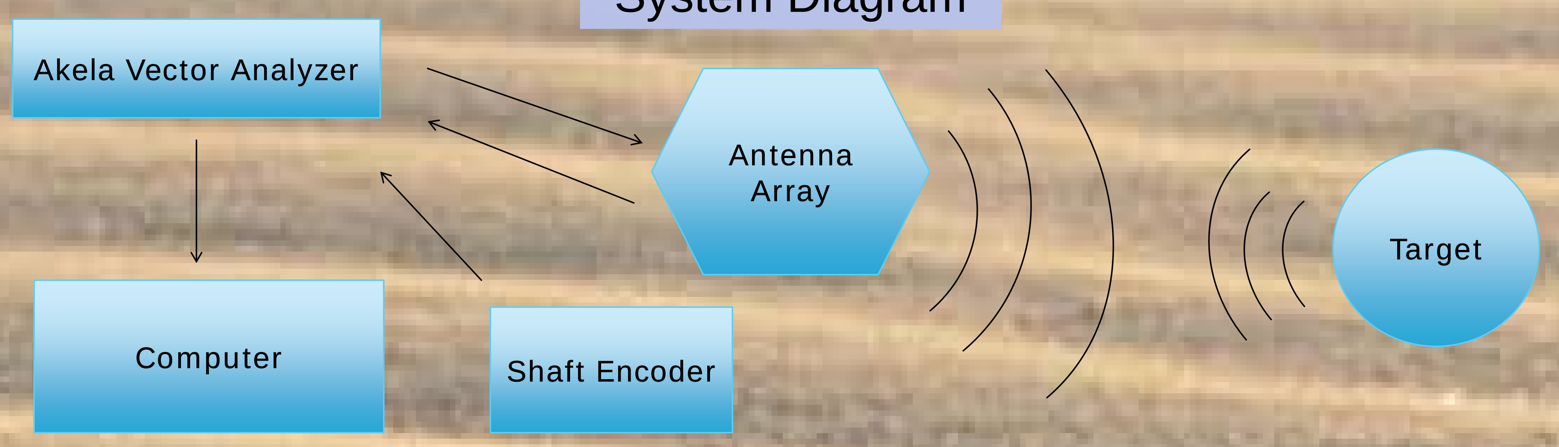
Project Overview

Many of the currently available SAR systems use a linear array of antennas, but this arrangement can become unwieldy as the number of antennas increases. Our goal was to create a more convenient system to make the technology more suitable for uses including mine detection, archeology, land surveying, and building inspection. We designed our system to use small antennas in a compact formation to make data collection easier. We then wrote code to produce images from collected radar data and developed an interface to open this technology to users without a technical background.



This is a comparison of the relative sizes of a linear array and hexagonal array both containing 7 antennas. The hexagonal array is less than half as wide and much shorter. This profile may be more convenient for taking data in the field.

System Diagram



System Specifications

Akela Vector Signal Generator and Measurement Unit

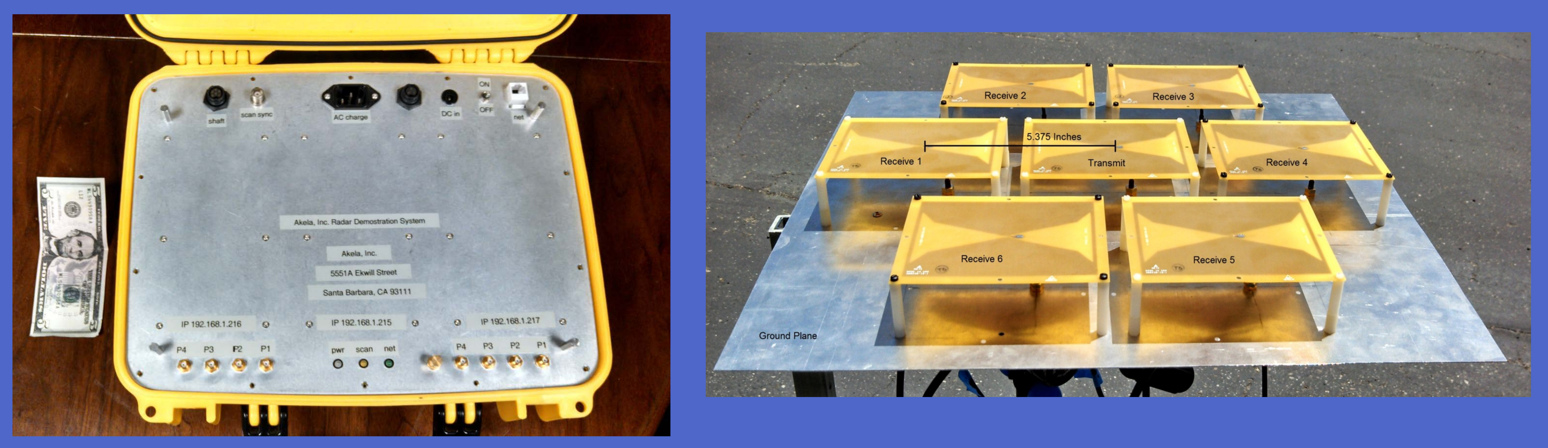
- Frequency Range – 500 to 2000 MHz
- Power output – 17 dBm nominal
- Communications Interface – 10/100 Base T Ethernet
- Sweep Synchronized Serial Data Interface (Shaft Encoder)
- 8 transmit/receive coaxial ports

Antenna Array

- 7 3"x4" Bowtie Antennas
- Arranged in a Regular Hexagonal Grid with 5.375" sides
- Shared Ground Plane
- Frequency Response – 700 to 2500 MHz
- 24"x18"

Shaft encoder

- 1024 data points per revolution

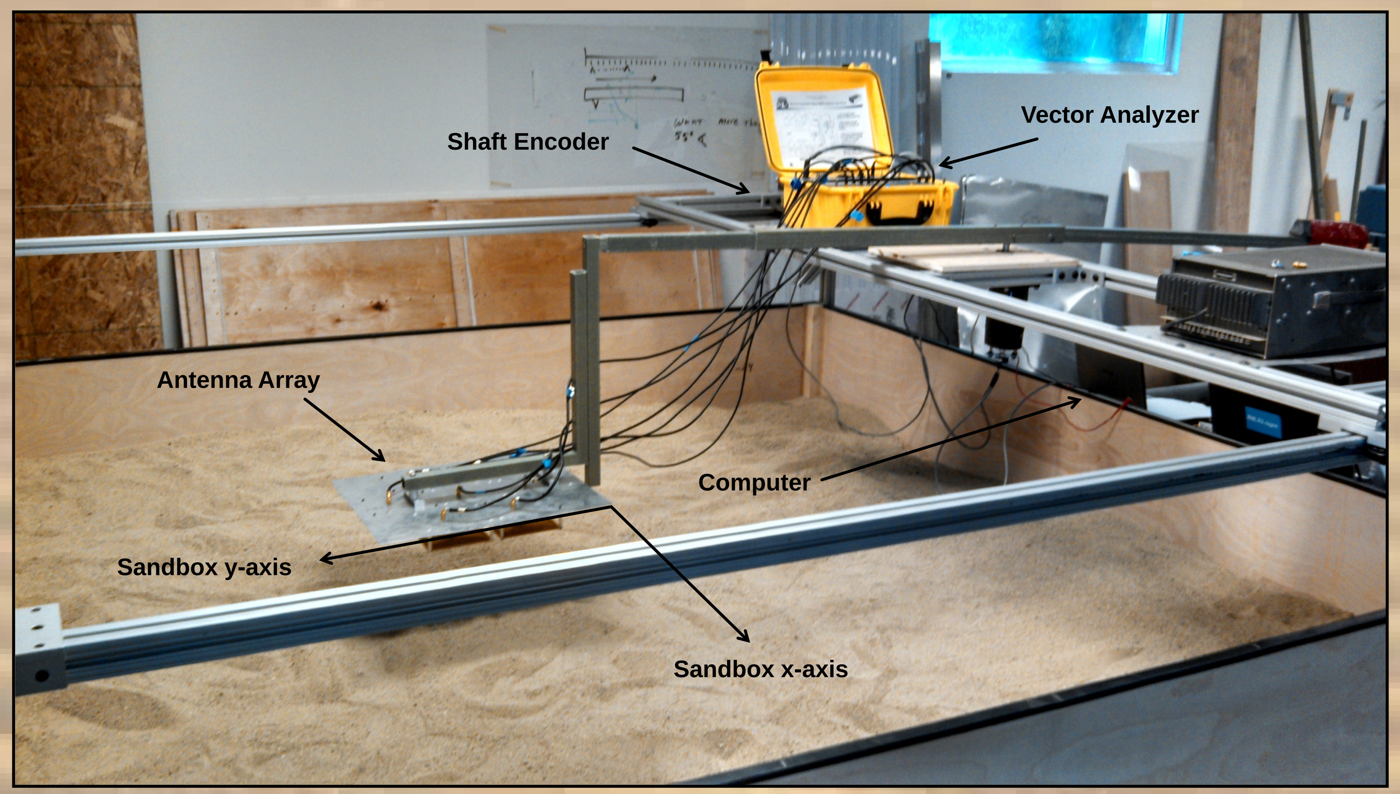


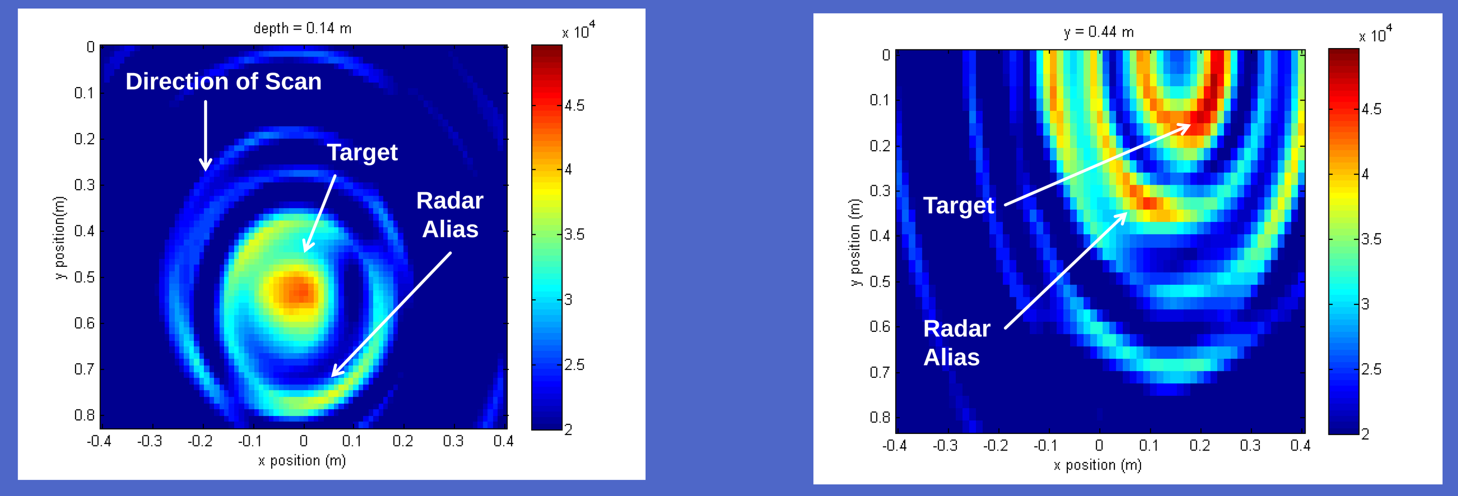
Right: Akela Radar Vector Analyzer. The Coaxial ports near the bottom interface with the antennas and the serial port at the upper right takes the shaft encoder values. The data is then sent to a computer via the Ethernet port at the upper right. This unit can be operated by battery or with power from a wall socket.

Left: Hexagonal Antenna Array. Seven 'bowtie' antennas were arranged in a regular hexagonal grid with a side length of 5.375". The antennas were attached to a shared ground plane to increase the directionality of the system. The antennas connect to the Vector Analyzer with coaxial connectors located on the other side of the ground plane.

Antennas

Our radar system used 7 antennas in a hexagonal grid to collect radar data. We used the center antenna as a transmitter and received from each of the outer antennas. We originally used planar log periodic antennas, but changed to the bowtie antennas pictured below because the original antennas suffered too much ringing. The new antennas have a shared ground plane to increase the directionality of the system. These antennas were provided by Akela inc. because antenna design is a complicated endeavor beyond the scope of this project.



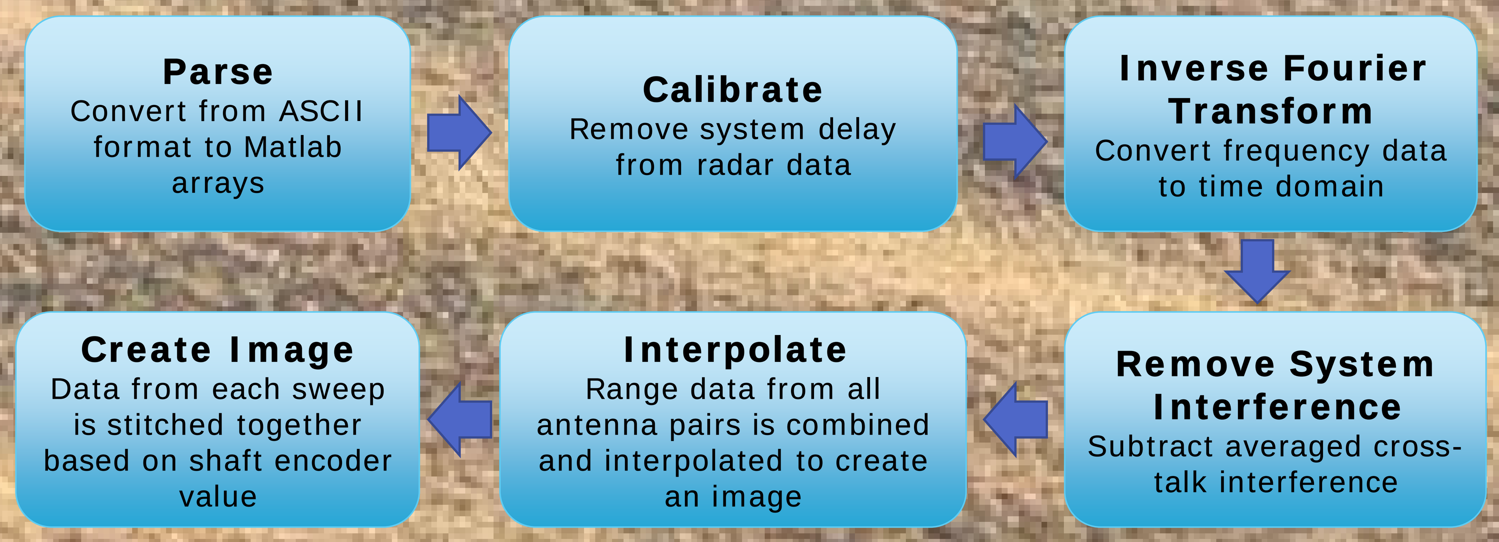


These are examples of the two ways our system can display data as an image. Both depict a metallic target buried in the sandbox pictured above at a depth of 0.14 m. The left image is in a plane parallel to the ground, and the second is in the x-z plane. Our system has a resolution that can discern separate targets that are further than 0.1154 m apart, and we use linear interpolation to smooth out the images. Radar alias and variation in the composition of the substrate cause the fringing noise around detected targets.

Imaging Algorithm

A number of steps are required to produce an image from the radar data. The first step was to import the data to Matlab and organize it into a multidimensional array. Next, prepared the data by subtracting the system delay and background interference. We then perform an IFFT to find the range data. We use the distance formula to calculate the travel distance for an echo from each antenna pair to each point in the imaging array. Finally, we sum the magnitude of the radar signal based on the travel distances we calculated. We can then take slices from the imaging array to display as images. When displaying an image we must scale the data with respect to the whole array in order to detect the targets.

Image Processing Flow Chart



Calibration

In order to accurately measure the locations of targets we needed to calibrate our system to remove the system delay. We found the system delay by taking range data from of a target at a known distance from the array to compare the measured distance to the actual distance.

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