Akela Ground Penetrating Radar (GPR) Reverse Engineering

A Major Qualifying Project (MQP) Report

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By:

Ravi Palmieri

Project Advisors:

Seyed (Reza) Zekavat

Douglas Petkie

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Introduction:

In this project we use an off the shelf radar (Akela radar) which has some limitations that need to be addressed. In order to address these limitations, we need to fully understand the Akela radar software in detail. We are looking to develop a radar of our own that does not have the limitations of the Akela radar, to provide optimal irrigation based on radar signals. We are motivated with this idea as farms today are not irrigating optimally meaning that they are either over or under-watering their soil. In this project we want to design a radar that can map signals into soil moisture so farmers can use predicted soil moisture and design irrigation systems optimally so they don't over-water. This radar is located and tested on a plot of land filled with soil here on our WPI campus.

My role is to understand the software of the Akela radar and convert its codes to python in-order to reverse engineer and backtrace to better understand the code and its connections with the radar components along with being able to then develop our own radar and deal with the limitations of the Akela radar which I will discuss later. The conversion of the code to python makes the code more accessible and adaptable which will help all others who engage with the software of the Akela radar. I am then able to create a flowchart that demonstrates these components and their connection to the Akela code.

Section 1: What Is a GPR Radar and What Does It Do?

GPR stands for Ground Penetrating Radar. It is a geophysical imaging technique that uses radar pulses to image the subsurface of the ground or other structures. The radar pulses are transmitted into the ground or other structures, and the reflected signals are measured by a receiver. By analyzing the time delay and amplitude of these reflections, GPR can create a subsurface image of the target.

GPR radar can be used for a variety of applications, including:

1. Archaeology: GPR can be used to locate buried objects, such as artifacts or structures, without excavation.
2. Geology: GPR can be used to image subsurface geological features, such as faults, bedrock, or groundwater.
3. Engineering: GPR can be used to locate underground utilities, such as pipes or cables, or to assess the condition of concrete structures.
4. Environmental science: GPR can be used to map subsurface soil moisture or to detect contamination.

In summary, GPR is a non-destructive imaging technique that can be used to create subsurface images for a variety of applications.

GPR software:

There are several software programs available for processing and interpreting GPR data. Some of the popular GPR radar software packages include:

1. GSSI RADAN: This software is developed by Geophysical Survey Systems, Inc. (GSSI) and is one of the most widely used GPR software packages. It offers advanced processing tools, data visualization, and 3D imaging capabilities.
2. MALA GPR Office: This software is developed by MALA GeoScience and is designed for processing and interpreting GPR data acquired with MALA systems. It offers a user-friendly interface, real-time data processing, and advanced data analysis features.
3. Sensors & Software EKKO_Project: This software is developed by Sensors & Software and is designed for processing GPR data acquired with their systems. It offers a range of data processing and interpretation tools, including 2D and 3D imaging, time slice analysis, and automatic target recognition.
4. IDS GeoRadar Oasis Montaj: This software is developed by IDS GeoRadar and offers a range of geophysical data processing tools, including GPR data processing and interpretation. It offers advanced visualization and processing capabilities, as well as integration with other geophysical data sets.
5. Proceq GPR Analysis Software: This software is developed by Proceq and is designed for processing GPR data acquired with their GPR systems. It offers a range of data processing and visualization tools, including 2D and 3D imaging, depth slicing, and waveform analysis.

These are just a few examples of the many GPR radar software packages available. The choice of software will depend on the specific needs of the user and the type of GPR system being used.

Section 2: What Is an Akela Radar?

To better understand an Akela radar, we need to know what an SFCW (Swept Frequency Continuous Wave) radar is. This is a type of radar that uses a continuous wave signal that is swept through a range of frequencies. The basic principle behind SFCW radar is that a signal is transmitted at a specific frequency and then the frequency of the signal is changed over time. The frequency change can be either linear or nonlinear. The transmitted signal is reflected by the target and the radar system receives the reflected signal. By measuring the time delay and frequency shift of the received signal, SFCW radar can determine the distance and velocity of the target.

SFCW radar is commonly used in applications such as ground penetrating radar, target detection, and distance measurement. It offers a number of advantages over other types of radar systems, including high resolution, accuracy, and sensitivity. One major disadvantage of SFCW radar is that it requires a complex signal processing algorithm to accurately determine the distance and velocity of the target. Additionally, SFCW radar systems are often more expensive than other types of radar systems.

The Akela AVMU500A is a 3D S-band radar system designed for maritime surveillance and navigation. It is produced by the Spanish company Indra and is primarily used for naval applications, such as on board ships, but can also be used on shore-based installations. The radar operates in the S-band frequency range, which is commonly used for maritime applications due to its ability to penetrate through adverse weather conditions such as rain, fog and sea clutter. The system uses an Active Electronically Scanned Array (AESA) antenna, which provides high resolution and accurate detection capabilities. The Akela AVMU500A offers a wide range of features, including 3D radar imaging, target tracking, and automatic radar operation. It also has a built-in Automatic Radar Plotting Aid (ARPA) system, which allows for the automatic tracking of multiple targets simultaneously. One of the unique features of the Akela AVMU500A is its ability to perform helicopter guidance and landing assistance. The radar is capable of providing precise altitude and position information to pilots during landing operations, making it a valuable asset for naval operations.

Overall, the Akela AVMU500A is a highly advanced and versatile radar system that is well-suited for a variety of maritime applications. Its high resolution and accurate detection capabilities make it a valuable tool for naval surveillance and navigation.

Section 3: Akela Radar Software, Structure, and Capabilities

SFCW or any radar has hardware and software components. The software structure of the Akela AVMU500A radar system is typically designed to include several modules that work together to provide the required functionalities. While the exact software architecture may vary depending on the specific version and configuration of the system, here are some of the modules that are typically included:

User Interface: This module is responsible for providing a graphical interface for the user to interact with the system. It may include features such as touch screen support, real-time display of radar data, and control of system settings.

Signal Processing: This module is responsible for processing the radar signals received by the system's antenna. It may include functions such as filtering, pulse compression, and Doppler processing.

Detection and Tracking: This module is responsible for detecting and tracking targets within the radar's coverage area. It may use algorithms such as Constant False Alarm Rate (CFAR) and Kalman filtering to perform these tasks.

Display and Visualization: This module is responsible for displaying radar data to the user in a meaningful way. It may include features such as 3D visualization, target highlighting, and data annotation.

Communication and Data Storage: This module is responsible for managing communication with other systems and storing radar data for later analysis. It may include features such as network protocols, file management, and data compression.

Calibration and Maintenance: This module is responsible for ensuring that the radar system is functioning properly and accurately. It may include features such as calibration routines, diagnostic tools, and system health monitoring.

The akela radar has certain limitations that I intend to synthesize to enable engineers to apply modifications to the software. These limitations include generating a fixed waveform, limited range resolution, and a fixed bandwidth of 300MHz - 3GHz. By reverse engineering, our goal is to develop our own radar and deal with the limitations previously stated. Overall, the software structure of the Akela AVMU500A radar system is designed to provide a reliable and user-friendly interface for performing a wide range of maritime surveillance and navigation tasks.

Section 4: Akela Radar Components

As previously mentioned, SFCW or any radar has a hardware and software component. This section will discuss its physical hardware components; these stages include transmitter, receiver, and signal processing unit, each of which include substages.

The transmitter has a signal generator which consists of a frequency synthesizer and a waveform controller. The frequency synthesizer generates a series of stable frequencies (f_1, f_2, …, f_n) over a specified bandwidth (B = f_n - f_1). The waveform controller controls the frequency stepping pattern, dwell time (Td), and the overall timing of the transmitted signal. The second component of the transmitter is the power amplifier which consists of a driver amplifier and a final amplifier. The driver amplifier amplifies the signal from the signal generator to an intermediate power level while the final amplifier further amplifies the signal to the desired power level (Pt) for transmission. The last component of the transmitter is the transmit antenna which radiates the amplified signal into the environment.

The next stage of the SFCW radar is the receiver which consists of a receive antenna, low noise amplifier (LNA), mixer, local oscillator, bandpass filter (BPF) / low pass filter (LPF), and an analog-to-digital converter (ADC). The receive antenna captures the reflected electromagnetic waves from the target. As for the next component, the low noise amplifier (LNA) amplifies the received signal while preserving the signal-to-noise ratio. The mixer consists of two components of its own, a down-conversion mixer and an IF amplifier. The down-conversion mixer mixes the received signal with the LO signal to produce an IF or baseband signal while the IF amplifier amplifies the IF signal before filtering. The next component of the receiver is the local oscillator (LO) generating a stable frequency reference signal used in the mixer. Another component being the bandpass filter (BPF) / Low Pass Filter (LPF) filters the output of the mixer to remove unwanted frequency components and noise. Lastly, the analog-to-digital converter (ADC) converts the filtered analog signal into a digital signal for further processing.

The final stage of the SFCW radar is the signal processing unit which consists of a digital signal processor (DSP) / FPGA, control unit, and display. The digital signal processor (DSP) / FPGA itself, consists of range gating which selects the portion of the received signal corresponding to a specific range window, and range processing which performs Fast Fourier Transform (FFT) or Discrete Fourier Transform (DFT) on the range-gated data to obtain frequency-domain data. Along with these components the DSP consists of velocity processing which calculates the doppler shift from the frequency data to estimate target velocity, and target detection applying detection algorithms, such as thresholding or Constant False Alarm Rate (CFAR) techniques, to identify target presence. Another component of the signal processing unit is the control unit which consists of a system controller which manages the overall radar system operation, including synchronizing the transmitter, receiver, and signal processing stages, and a user interface which enables user interaction with the radar system for configuration and control. Lastly, the display component of the signal processing unit visualizes processed information, such as target range, velocity, and other relevant parameters.

The following are some formulations of specific terms just discussed that help with overall understanding of the radar and its components as previously mentioned. The range resolution (ΔR) is the minimum distance between two targets that can be resolved by the radar. It is determined by the bandwidth (B) of the transmitted signal:

$\Delta R = \frac{c}{(2 * B)}$, where c is the speed of light.

The maximum unambiguous range (R_{max}) is the maximum range at which a target can be detected without ambiguity.

$R_{max} = \frac{(c * T_d)}{2}$, where T_d is the dwell time of each frequency step.

The frequency step (Δf) is the difference between two consecutive frequency steps.

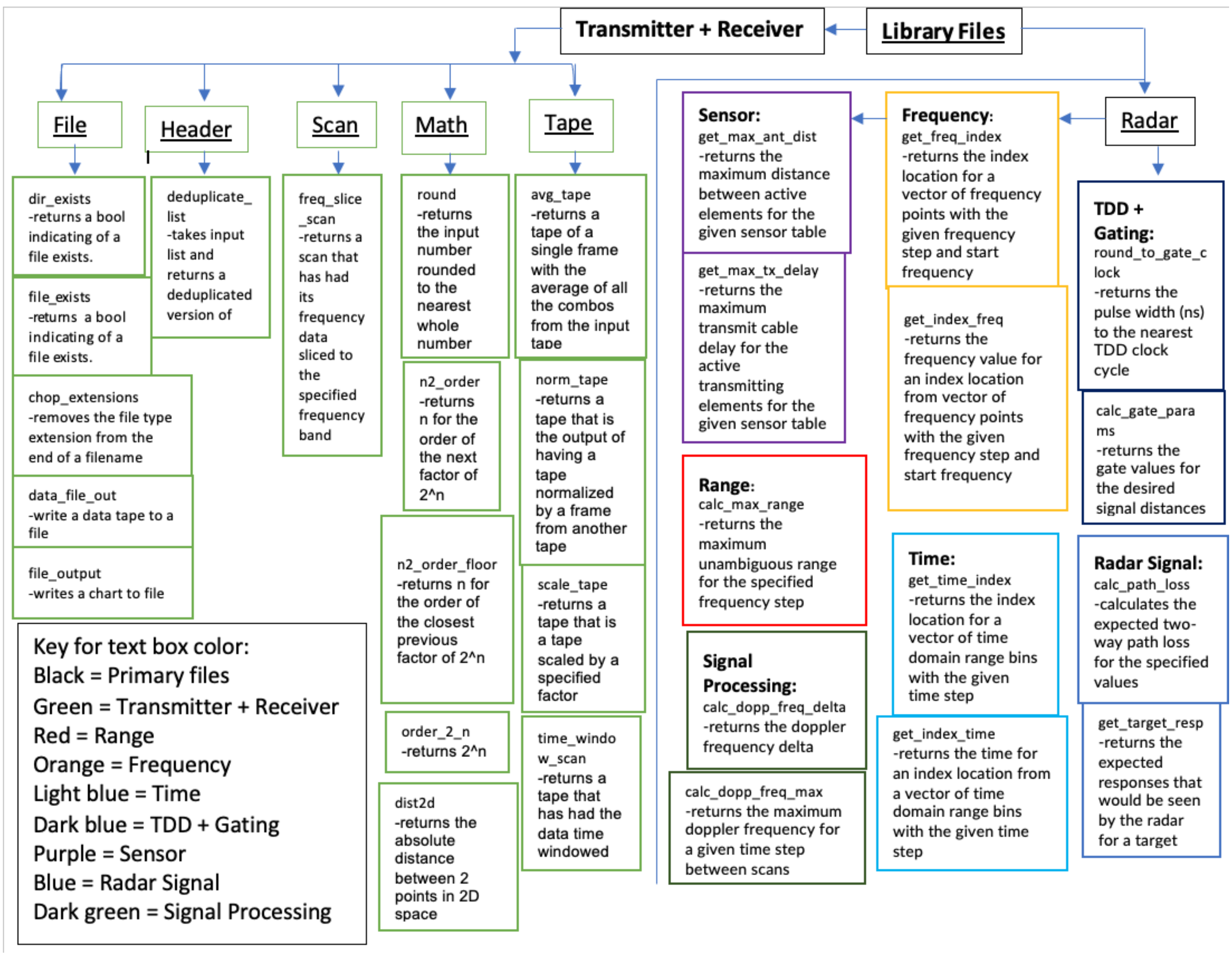
$\Delta f = \frac{B}{N}$, where N is the number of frequency steps.

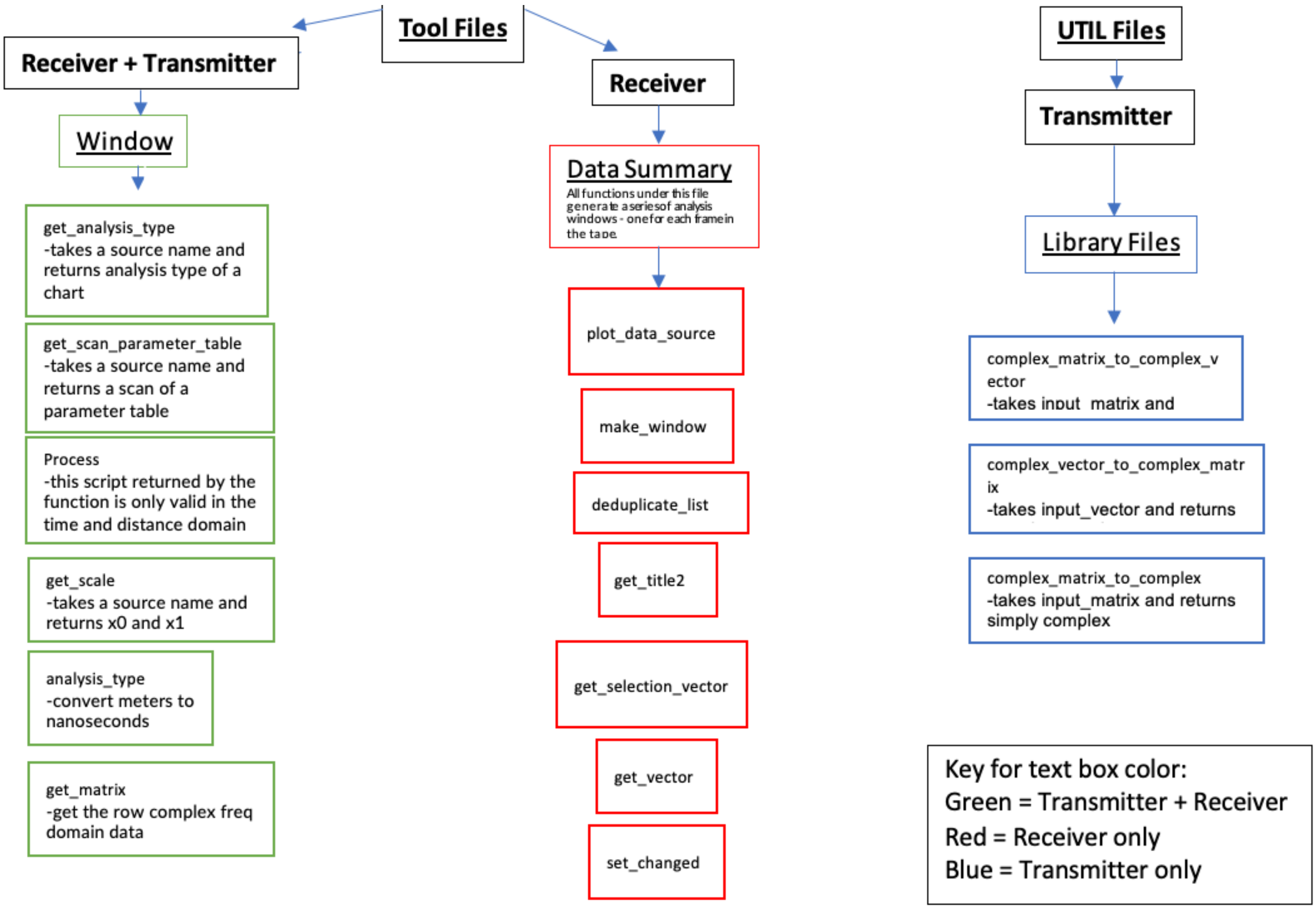
The range gate width (RGW) is determined by the desired range resolution.

$\mathrm{RGW} = \frac{c * T_g}{2}$, where T_g is the range gate duration.

Section 5: Akela Code Block Diagram Connection to Radar Components

Code Block Diagrams (simplified versions):





Specific, important Akela software codes were transferred from C++ to python for reverse engineering purposes in-order to backtrace to find a potential main function, understand the function and connection of the codes, and to make a connection of the different method files with the components of the Akela radar itself. The code files looked at and altered were Library (Lib), Tool, and Utilization (UTIL) files. Under these code files there are other sub-files that contain code that is very important to the processing of the transmitter, receiver, and/or signal processing unit of the Akela radar. Certain limitations of the Akela radar can be scoped out into certain files which are now separated into sections in relation to the hardware components. For example if there is a sensor problem, we know where to find that section of code as seen in the flowchart figure. The transmitter and receiver specific files included the following code files: File, Header, Scan, Math, Tape, String, Type, Plot, and Table. The Radar subfile under the Library files contained code that pertained to the following components: Range, Frequency, Time, TDD + Gating, Sensor, Radar Signal, and Signal Processing. As for the Tool files, the subfile Window pertained to the receiver and transmitter while the subfile data summary pertained to the receiver only. Lastly, UTIL files had to do completely with the transmitter component of the Akela Radar. These were the mechanical component connections that were possible to make between the Akela radar and the python codes.

Conclusion:

Looking into the future, our goal is to use drones in order to measure moisture content in the subsurface of mega farms. Moisture probes would not help us solve the problem since they measure moisture at a certain point which makes them not suitable for mega farms. In order to do this, we need to use machine learning to measure moisture levels and we want to map the radar information signals into moisture tracking. The apparatus we want to use to do that is a radar that can be installed on drones; in order to do that we need to extract features of drones and use machine learning to implement them.

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