Using Simulations and Computational Analyses to Study a Frequency-Modulated Continuous-Wave Radar

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ABSTRACT

This paper describes a method for simulating Frequency-Modulated Continuous-Wave (FMCW) radar. The developments presented target classroom lectures and can form the basis of student projects. Computational analysis and simulation are critical elements of science and engineering education in which students need to acquire these competencies. FMCW radar system simulations are an example of a real-world application, invested in rich mathematical/physical content that exercise these competencies. Unlike conventional radars that operate in the time domain, FMCW radars operate in the frequency domain. Spectral and phase analyses are required to infer range and the range resolved velocity of meteorological targets such as rain or drizzle. Hence to proceed with simulations, students are first introduced to signals processing topics such as discretization and sampling of signals, Fourier Transforms, Z-transforms, and filters. Computations and the display of results are subsequently performed using Elanix System Vue and Matlab software. To aid the interpretation of the results, a brief description of FMCW physical principles of operation is provided. The computational technique is general and efficient, allowing the range-resolved radial velocity component of precipitation to be computed in real-time. Simulations of range are in excellent agreement with field test measurements of experimental, operational X-band radar currently being evaluated at NASA Goddard Spaceflight Center while computations of the range-resolved velocity component of precipitation agree with the setup conditions of the simulations.

KEYWORDS
Doppler Effect, Fast Fourier Transforms, FMCW Radar, Remote Sensing, Simulations and Computational Analyses

INTRODUCTION

This radar is designed at Colorado State University in order to detect precipitation (rain and snow) at high spatial resolution over relatively short ranges (e.g. 33 km). However, this type of radar is not new. Much credit demonstrating the use of FMCW in remote sensing with applications to atmospheric science is credited to Miller and Strauch (Miller, 1974). The advantages of FMCW radar are: (1) low cost, (2) good sensitivity, (3) high spatial resolution, (4) high reliability, (5) portability, (6) relative simplicity and (7) safety. This type of radar can reduce blind spots (or gaps) of conventional pulsed-
Doppler radars and is useful for providing input observations to evaluate meteorological models, either directly or as a component of a profiler system to retrieve information on precipitation in the liquid or ice phase as well as providing input to numerical weather prediction models.

Also, FMCW radar can be used to measure exact height of landing aircraft. The advantage of using these radar signals is that the object target velocity and range can be quickly calculated using Fast Fourier Transforms (FFT). FFT is a commonly used signal-processing technique that converts time-varying signals to their frequency component. The FMCW radar transmits a frequency signal and then receives a signal after it hits a target and returns. Then, the transmitted signal is mixed with the received signal, and takes FFT of the mixed signal to extract information about the range as well as the Doppler effect of the target. Hence the radar sends a continuous signal; therefore, the sampling of the signal is done over a series of time intervals. The Doppler effect of the target refers to the shift in frequency due to the movement of an object toward or away from the receiver. FFTs transform data from the time domain to the frequency domain so that information about frequency and periodicity can be easily extracted.

This type of radar is very mobile, inexpensive, detects precipitation, and is very beneficial for detecting targets at short ranges. This is important because these types of radars can be deployed over large areas for testing and data collection (Stove, 1992). FFTs have been used dating back to 1805, when Carl Friedrich Gauss used FFTs to evaluate orbits of the asteroids Pallas and Juno (Heideman, 1985). This radar is used in various fields and experiments such as the tracking of hurricanes, tornados, and storms by meteorologist, and detecting planes and other objects in the air by the Air Traffic Control (Khain, 1999).

Simulations have been used successfully for teaching engineering content in a real world project. Implementing simulation in classroom will increase understanding of how a real world system works. Two of the most promising roles of simulations in instruction are to: 1) establish a cognitive framework or structure to accommodate further learning in a related subject area, and 2) provide an opportunity for reinforcing, integrating and extending previously learned material (Brant, 1991). In this study, students receive the simulation as a framework for understanding the concept of radar after formal classroom instruction.

**METHODOLOGY**

All FMCW systems use the same basic concept, and the three types (three different modulation schemes) only differ in the signal processing performed on the FFT. The process is shown graphically in Figure 1 and the system model is as follows:

1. Calculate transmitted signal.
2. Calculate received signal.
3. Mix signals (multiply in time domain).
4. Two sinusoidal terms are derived; filter out one.

**Figure 1. FMCW radar**
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