Using LabVIEW, PXI, and DIAdem to Create an FMCW Phased Array Radar for Avalanche Imaging

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Avalanches pose a significant threat to human life and settlements, so studying them is key to formulating risk zones. Previously, validating models in order to predict avalanche behavior was limited by a lack of high-quality field data. We can use radar sensors to gather field data, but in their current form, they only provide single-dimension range measurements. The transmitter power also limits them to a range resolution in the order of 50 m, which is too coarse to provide a true representation of the avalanche dynamics.

This project studies the underlying dynamics of avalanche flows with the aid of a newly developed frequency modulated continuous wave (FMCW) phased array radar. With this unique radar, we now can produce high-resolution 2D velocity measurements and a fully animated 2D reconstruction of avalanche events. The project involves several institutions: University of Sheffield, University of Cambridge, and University College London (UCL). At UCL, we worked on radar system development and the associated radar signal processing.

The radar operates in a reinforced concrete bunker at a well-equipped avalanche test site in Switzerland, Vallée de la Sionne (VDLS). The bunker is positioned at the foot of a slope opposing the avalanche track and provides protection for our radar equipment. We use the test site to study avalanche processes using an array of sensors such as radar, pressure sensors, and acoustic sensors. We can artificially trigger avalanches for experimental measurements by setting off explosives at the peak of the mountain after heavy snowfall. The site is also prone to natural avalanches that we can measure with instruments that are automatically triggered by acoustic sensors.

Data Acquisition and Radar Control

Several specialized data acquisition systems appeared to meet our design requirements, however, only a National Instruments solution offered tight enough integration between our hardware and software for this project to succeed. We purchased an NI PXIe-1082 chassis combined with an NI PXIe-8130 controller, and an 8-channel, 16-bit NI PXIe-6366 X Series DAQ device with specifications that met our data throughput and dynamic range requirements. Combined with a fast, solid-state drive from a third party, the system can measure entire avalanche events (expected to last at least two minutes), without data loss or buffer overflows.

System cooperation with LabVIEW was vital for system software design. We needed the radar to operate throughout the winter without fail, so software reliability was critical. The radar also interfaces with a triggering system at the avalanche test site bunker. We used NI telephone and in-person support to quickly configure LabVIEW to detect a trigger and begin our data acquisition, and also to control relays to turn on our radar transmitter. We extensively tested the software based on LabVIEW before deployment to prove its reliability. Software development went so smoothly that we saved crucial development time and our system was up and running for the avalanche season.

Radar Design

The radar developed at UCL follows an FMCW design, which carries out ranging by mixing the transmitted linear frequency modulated (LFM) signal with the received return signal. This mixing process produces a frequency difference (beat frequency) to extract target range and velocity information. In this case, the radar operating frequency is 5.3 GHz, chosen to illuminate the underlying dense region of the avalanche.

Our FMCW radar provides sub-meter range resolution with a relatively low transmitter power because the transmitted signal has a wide bandwidth (200 MHz) and the radar continuously transmits. The mixing process also compresses all the signal energy into a very small bandwidth, which reduces the strain on the receiver acquisition hardware relative to other pulse compression techniques.

The UCL radar has eight receiver channels to provide horizontal resolution for the first time (hence, the radar produces 2D images). The eight receiver antennas are randomly spread across a wide 5.3 m aperture for a horizontal resolution of c. 10 m at 1 km range.

The radar has a maximum range of c. 3 km to image the entire avalanche track. To satisfy this requirement, we used the NI PXIe-6366
DAQ device, which is capable of simultaneously acquiring data on eight channels at the 2 MS/s sampling rate we required. Estimates of cross-coupling between the radar transmitting antenna and the nearest receiving antenna means the radar had a dynamic range requirement of c. 80 dB; therefore, the receiver A/D converter required an effective number of at least 14 bits.

Avalanche Measurements

After the system acquires measurements from an avalanche, it processes the recorded radar data entirely offline. To make the processing more memory efficient (the datasets are very large), the data is split into segments using NI DIAdem and its visual basic script (VBS) functions. DIAdem conveniently exports the segmented data in a format that third-party software can read directly. Each receiver channel initially processes collected data separately. By performing a moving-target indication on the data, we can filter out nonmoving targets and isolate targets associated with the moving avalanche. The intensity of each pixel in the image is proportional to the return signal strength of the moving target.

Conclusion

Using tightly integrated NI LabVIEW software and PXI Express data acquisition hardware, we successfully made measurements of three natural avalanche events during the winter and expect to record more data. Future plans involve applying techniques to track the avalanche front so we can measure the avalanche velocity using Doppler information. Our velocity estimates will be validated against data collected by other radar instruments buried within the avalanche track. The ultimate goal is to produce 2D animations of entire avalanche events with a frame rate of 50 frames per second.

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Figure 1. Radar antenna arrays at the VDLS bunker

Figure 2. Simplified block diagram of FMCW phased array radar
Figure 3. Range-time MTI image of 6th December avalanche event

Figure 4. Aftermath of natural avalanche event at VDLS with regions of movement highlighted
**Next Steps**

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