Initial Results of a Low-Cost SAR: YINSAR

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Abstract— Synthetic Aperture Radar (SAR) is being widely used in a variety of studies. High instrument purchase and operation costs remain a limiting factor in SAR technology. We have developed a compact, low-cost inteferometric SAR system known as YINSAR which flies on a small aircraft. YINSAR operates at 9.9 GHz with a 200 MHz bandwidth. This paper presents recent results from YINSAR test flights. Sample images and a brief analysis of the effective resolution are presented.

INTRODUCTION

Spaceborne and aircraft-borne Synthetic Aperture Radar (SAR) instruments have been shown to be effective in a variety of remote sensing applications. SAR images are widely used in land use studies and for mapping vegetation. By using interferometric SAR, both radar imagery and vertical topography can be obtained, further increasing the utility of SAR systems. However, the high cost of construction and operation of SAR instruments is a limiting factor in their wider use, particularly for applications requiring multiple revisits. A SAR with low operating costs could make SAR data more available to the research community and spur the development of even more applications. To this end we have developed an experimental compact, low-cost interferometric SAR.

This paper briefly describes our SAR system, YINSAR, and presents image results from a recent flight test. After a brief introduction and discusson on resolution, several targets are selected from actual data and analyzed to evalute the effective resolution of the system. The results suggest that even without applying motion compensation, YINSAR can achieve close to its theorectical resolution of 0.75 m in range and 0.1 m in azimuth.

YINSAR DESCRIPTION

YINSAR is an interferometric radar system operating at 9.9 GHz with a 200 MHz bandwidth designed for low-altitude operation from a small aircraft. The system incorporates an all-digital IF and a multi-sensor, high-precision platform motion measurement system. A Cessna Skymaster serves as the YINSAR platform. It is a dual-engine, four-passenger, propeller-driven plane, with low operating costs. The YINSAR instrument consists of three boxes. Each rack mount box is approximately $17 \times 19 \times 7$ in ($43 \times 48 \times 18$ cm). For photos of YINSAR and its platform along with a detailed description of the instrument, the reader is referred to [1].

All together YINSAR weighs approximately 150 pounds, essentially the weight of a passenger. At full power the instrument consumes 600 W and is powered by the aircraft alternators through a DC to AC inverter. YINSAR uses three slotted-waveguide antennas that are mounted to the bottom of the aircraft (1 transmit and 2 receive). The beamwidths of the antennas in the azimuth and range directions are 9 degrees and 40 degrees respectively.

A single operator in the copilot's seat operates the system via a graphical interface program running on a laptop computer. The operator can adjust several parameters that change the performance of YINSAR and perform tests to verify the proper operation of YINSAR while in flight.

The YINSAR instrument is undergoing flight testing. In this paper we present single-channel SAR images.

THEORETICAL PERFORMANCE

YINSAR operates at a center frequency of 9.9 GHz. The range chirp bandwidth is 100 MHz and is double sideband modulated to yield an effective chirp bandwidth of 200 MHz. This results in an approximate range resolution for YINSAR of:

$$\delta_r \approx \frac{c}{2(BW)} \approx 0.75m$$

(c is the speed of light and BW is the effective chirp bandwidth).

Since YINSAR flies in a small aircraft, it can be flown at a low altitude (< 3000 ft) allowing the use of smaller antennas for a given transmit power while achieving good image SNR. Smaller antennas also yield better azimuth resolution. With an antenna length of 20 cm, the theoretical resolution of YINSAR in azimuth is:

$$\delta_a \approx \frac{L_a}{2} \approx 0.1m$$

(L_a is the length of the antennas in the azimuth direction).

INITIAL RESULTS

The data discussed in this section is from a test flight over Cache Valley, UT, on March 27, 2000. Sample images of various types of terrain are shown in Figs. 5 and 6. The data is collected at a platform altitude of approximately 305 m (1000 ft). The platform velocity varies over the entire flight from 45–66 m/s and data collection is performed at 1000 Hz PRF (pulse repetition frequency).

The data presented in this paper has not been motion compensated. While we have observed motion induced problems in

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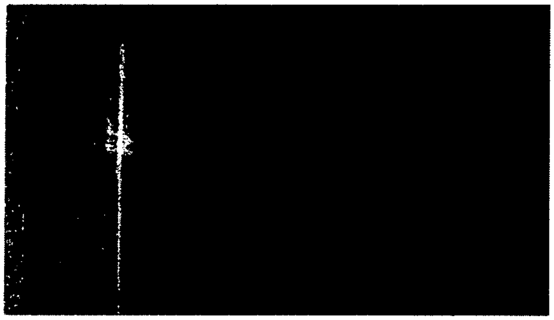

Figure 1: A YINSAR 1×1 look image of target 1.

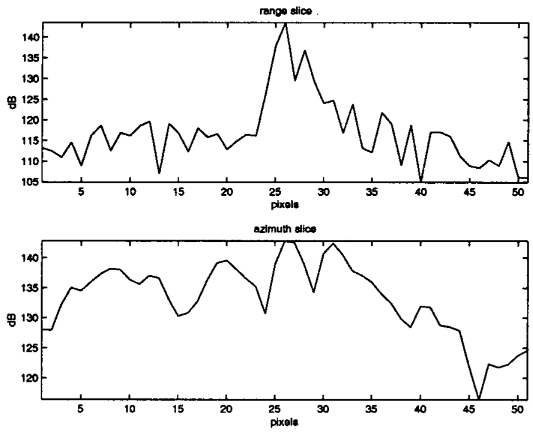

Figure 2: The range and azimuth response of target 1.

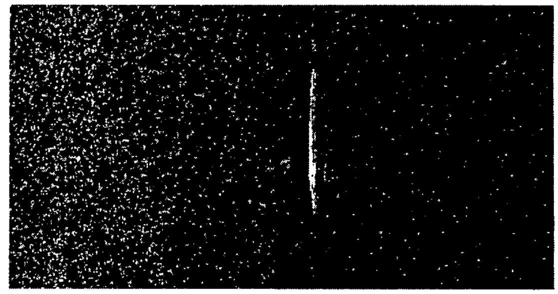

Figure 3: A YINSAR 1×1 look image of target 2.

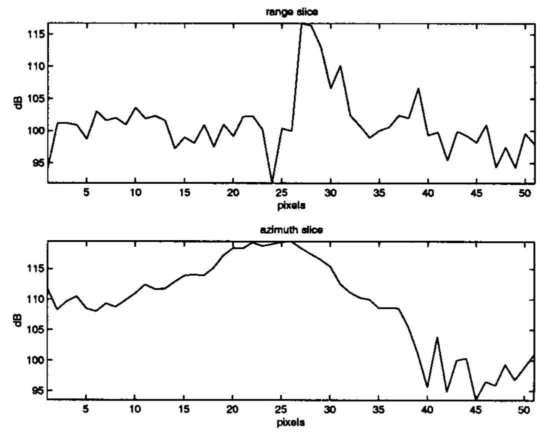

Figure 4: The range and azimuth response of target 2.

the imagery, it is clear by carefully flying the plane during data collection that motion effects can be minimized. Nevertheless, precision motion data is collected by YINSAR and applying motion compensation will improve image quality and utility. The motion data is measured by multiple GPS systems and an IMU (inertial measurement unit). The GPS systems consist of a kinematic GPS (attitude) unit and a differential GPS postion unit both with a measurement rate of 10 Hz. The IMU uses gyros to measure angular rotation rates at 1 kHz and accelerometers to measure linear accelerations at 500 Hz. These are combined to compute high precision pointing and position information for the aircraft.

In the images shown below, the platform moves from the top of the image towards the bottom. The horizontal axis is the range axis and the vertical axis is the azimuth axis. Each image is displayed so that the left side of the image is nearest in range with the right side being greatest in range from YINSAR.

The YINSAR image pixel size is determined from its operating parameters. The timing of the pulse return sampling is such that each single look image is 0.6 m per pixel in the range direction. The pixel size in the azimuth direction depends on the velocity of the airplane divided by the PRF of the radar. For a platform velocity of 50 m/s and PRF of 1000 Hz, the azimuth pixel size is 0.05 m. The targets analyzed in this paper are chosen because they are bright (highly reflective) and small compared to the surrounding areas of each SAR image. They are assumed to be point targets.

Target 1 is shown in Fig. 1. The resolution in the range direction is determined from using a 1×2 look image i.e., 2 azimuth pixels are averaged and the image is downsampled to 0.6 m in range and 0.116 m in azimuth pixel size. The range response of target 1 is shown in Fig. 2. Using linear interpolation the 3dB width is 1.49 pixels yielding a range resolution of 0.87 m. This result is within 16% of the theoretical limit of the YINSAR range resolution.

To estimate the azimuth resolution, a 2×1 look image is analyzed. The azimuth response of target 1 (see Fig. 2) shows several peaks near each other. These different peaks are believed to result from motion-induced blurring of the target. Consequently the 6 dB width is used instead of the 3 dB width to estimate the azimuth resolution. The 6 dB width is 27.53 pixels and each pixel is 0.058 m in azimuth resulting in an estimated azimuth resolution of 1.6 m.

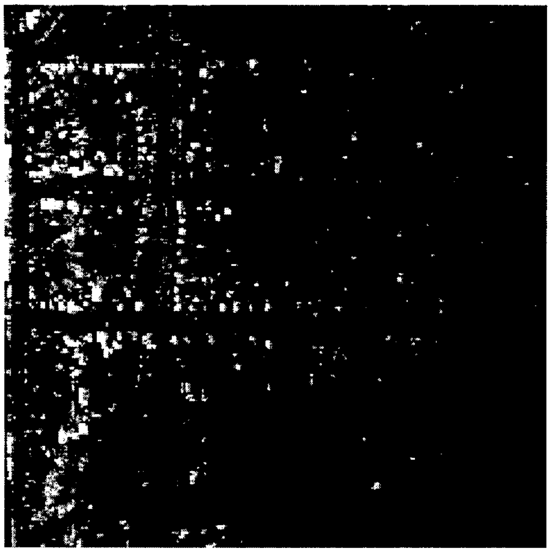

Figure 5: An image of a section of Logan, UT with pixel size of 1.2 m square.

For comparison, target 2 shown in Fig. 3 is also analyzed to estimate YINSAR resolution. The range and azimuth response are plotted in Fig. 4. Using a 1×4 look image, the range resolution is 1.98 pixels or 1.19 m. For the azimuth response, a 2×1 look image yields a 3 dB width of 10.4 pixels or 0.59 m. This target appears to suffer less from the effects of the aircraft motion than target 1.

Finally, in the next figures YINSAR images are shown over differing types of terrain. A small, urban scene is shown in Fig. 5 with a pixel size of 1.2 m square. Objects such as buildings, streets, trees, and cars are readily seen.

Another image (Fig. 6) comes from farmland. It is processed to a pixel size of 0.6 m square. In the image one can see several trees and roads. The dark area is a river, and the fuzzy spots on the river are vegetation near the river surface.

A wider variety of images can be found at the BYU MERS (Microwave Earth Remote Sensing) website:
www.ee.byu.edu/ee/mers/yinsar/index.html.

In addition to single-channel images, YINSAR has been used to create interferograms. Future improvements to the YINSAR images will include interferometry and motion compensation.

SUMMARY

The resolution of YINSAR images without motion compensation is estimated as $\sim$ 1.0 m in range and $\sim$ 1.0 m in azimuth. In addition, interferograms with visible changes in phase have been created with YINSAR. It is anticipated that motion compensation will improve the resolution of single-channel images and the quality of interferograms. These results show the potential use of YINSAR as a low-cost SAR.

Figure 6: An image of a road and river in Cache Valley, UT, with pixel size of 0.6 m square.

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References

[1] Douglas G. Thompson, David V. Arnold, and David G. Long. YINSAR: a compact, low-cost interferometric synthetic aperture radar. In *Proceedings of the 1999 IEEE International Geoscience and Remote Sensing Symposium*, pages 598–600, Germany, Jun 1999.