YINSAR: a Compact, Low-Cost Interferometric Synthetic Aperture Radar

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Abstract— Synthetic Aperture Radar (SAR) has proven useful for many different applications. Many more applications would be possible with a low-cost instrument. To address this need, BYU has developed its interferometric SAR, YINSAR. This compact, low-cost system is operated from a four passenger aircraft. This paper reports the current status of YINSAR. The system operation and instrument platform are described in detail. The motion measurements and their statistics are discussed.

INTRODUCTION

In recent years, Synthetic Aperture Radar (SAR) images and interferometric SAR (IFSAR) images have found application in many different fields of study. Many more applications of SAR and IFSAR are possible with appropriate instruments. A small SAR with low operating costs could provide wider access to the scientific community. To address the need for such instruments, Brigham Young University has developed YSAR [1] and YINSAR. YSAR was a prototype built "on a shoestring" and showed the feasibility of small SAR. YINSAR is the second generation system which improves upon many design aspects of YSAR. Both systems have low cost and simple design because of the use of commercially available analog and digital parts for most components.

This paper reports the current status of the YINSAR instrument. The following section gives an overview of the YINSAR instrument and gives the current status. The next section gives some details on the measurement accuracies in the motion measurement system.

YINSAR INSTRUMENT AND PLATFORM

YINSAR is an interferometric system based in part on the YSAR design [1]. The block diagram is shown in Fig. 3. The custom RF subsystem was built with special care to improve robustness and signal-to-noise ratio. The motion measurement and compensation system combines differential GPS with inertial measurement. A micro-controller unit controls subsystem power supplies, thus reducing the load when not collecting data. The entire system is controlled through a graphical interface on a laptop computer.

The YINSAR platform is the Cessna 337M shown in Fig. 1. This is a four-passenger, dual-engine aircraft. The radar hardware will share the space of the two rear seats with other remote sensing instruments. The front seats will be occupied by the pilot and the radar operator.

Figure 1: The YINSAR platform is this four-passenger Cessna 337M.

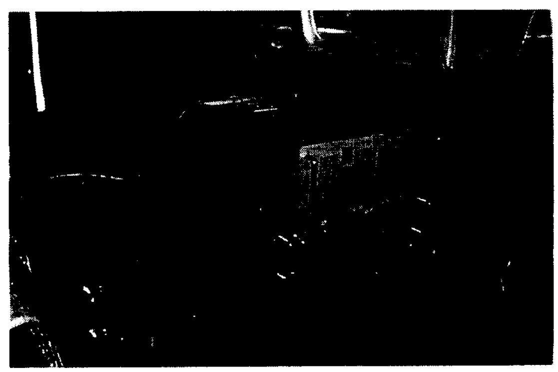

Figure 2: Photograph of the YINSAR equipment inside the aircraft.

The YINSAR instrument resides in three $17 \times 19 \times 7$ inch ($43 \times 48 \times 18$ cm) rack-mountable boxes, mounted in the rear of the aircraft as shown in Fig. 2. These boxes respectively contain the computer, the RF/IF subsystem and system controller, and the motion measurement subsystem. All of the antenna connections and subsystem interconnections are made on the back of the boxes, and there are simple debugging displays and controls on the front. The system consumes approximately 600 W in full-power operation.

The radar looks to the left of the platform so that the pilot can see the area being imaged. The antennas are horns fed by a slotted waveguide array. These are mounted on a bracket below the aircraft as seen in Fig. 4, giving a baseline of approximately 1 m horizontal. The 10-slot array forms the beam in the azimuth direction, and the horn forms the beam in the

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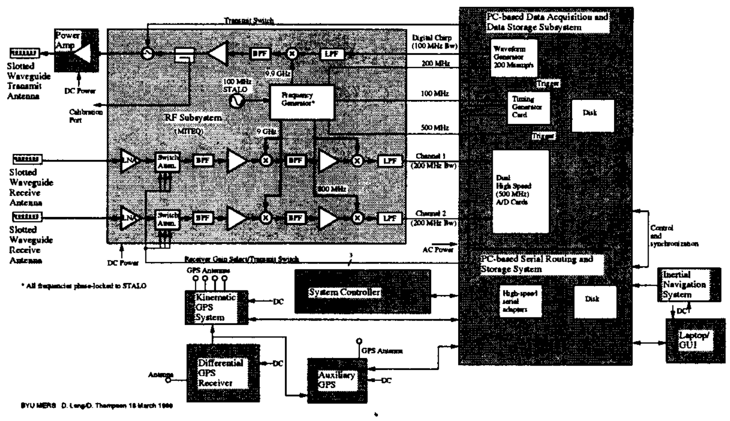

Figure 3: YINSAR Block Diagram

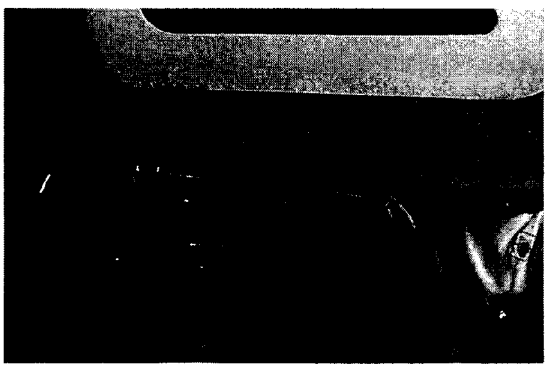

Figure 4: Photograph of the YINSAR interferometric antenna mounts.

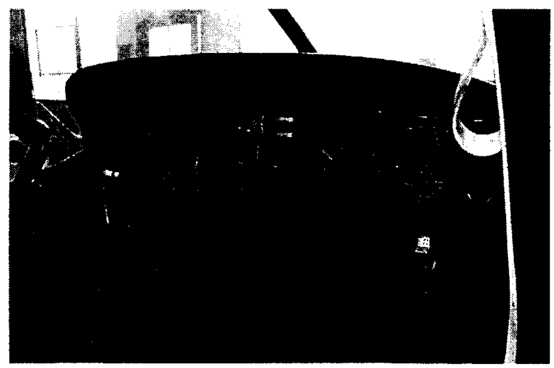

Figure 5: Photograph of the cockpit including the laptop and its graphical user interface.

range direction. The beamwidths are 9 and 40 degrees in azimuth and range respectively. The transmitter output is 10 W.

The system is operated from a graphical interface on a laptop computer held by the operator, as shown in Fig. 5. This interface includes a map of the area to be imaged and shows the current position on this map. The software allows the operator to specify desired paths and assists in following these paths. The laptop is connected via a serial interface to one of the two Pentium-based computers in the computer box. This computer is called the communications computer and is dedicated to routing and storing serial data, with six communications partners: laptop, power subsystem controller, SAR computer, differential GPS, kinematic GPS, and inertial measurement unit. The SAR computer is dedicated to collecting SAR data. In addition to the dual high-speed analog-to-digital converters, this computer contains the timing generation subsystem. The two computers are synchronized through a parallel port connection when starting data collection, which allows the radar and motion data to be properly timestamped.

The resolution of the interferometric images is expected to be better than 1 meter in all three directions. With a 100 MHz double sideband chirp, the effective bandwidth is 200 MHz and range resolution is on the order of a meter. This system is currently in the final stages of ground testing. While we had hoped to have images at the time of publication, these were not available due to delays in refurbishing the aircraft and obtaining FAA certifications.

MOTION MEASUREMENT ANALYSIS

Motion compensation is critical for accurate interferometry and is complicated by a small aircraft which exhibits significant motion. The motion measurement system for YINSAR consists of a differential GPS (DGPS), a kinematic GPS (KGPS), and an inertial measurement unit (IMU). This section discusses the error statistics for these data sources and our plans for combining them to make motion estimates.

The DGPS provides measurements of velocity and position at a rate of 10 Hz. Single sample standard deviations range from 8 to 23 cm/s for velocity and 20 to 80 cm for position.

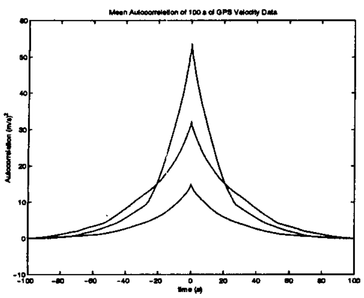

Figure 6: Average autocorrelation of DGPS velocity components. The autocorrelation of 100-second segments was found, and these result were averaged.

Figure 6 shows the autocorrelation function for the three velocity components calculated from a particular seven-hour data set. These measurements are highly correlated, so reducing the error requires averaging a large number of measurements.

The KGPS provides measurements of Euler platform attitude angles at a rate of 10 Hz. The single sample error values range from 0.08° to 0.3° in different tests. Like the DGPS measurements, these values are correlated enough that the error cannot be significantly reduced by averaging a few measurements.

The IMU provides measurements of angular rotation rates at 1kHz and linear accelerations at 500 Hz. The noise in the raw measurements is dominated by quantization noise, but the data is quantized in a special way which makes most of the quantization error disappear in the integration. Raw accelerometer data has a standard deviation of 20mG, but the position error corresponds to a noise value of only 3mG.

These motion data sources will be combined to make the most accurate motion estimates possible. First the attitude is estimated as a function of time. This is done by integrating the gyro data, with the start angle estimated from a combination of gyro and KGPS data. Next the accelerometer measurements are rotated into the global reference frame and integrated. The average velocity and average position are determined from the DGPS data. The accelerometer integration is done in short segments. The segment length is a tradeoff between DGPS velocity error, which decreases if the measurements are averaged over a long time, and the integrated accelerometer error, which increases as a nearly quadratic function of time. Finally the segments are pasted together to form estimates of position and attitude for each pulse in the image.

SUMMARY

There are many applications well-suited to low-cost SAR, including geological, archaeological, and commercial uses. The success of YSAR has demonstrated that such systems can produce useful images . YINSAR improves on the design of YSAR in many ways and is expected to produce images which are better and more useful.

ACKNOWLEDGEMENTS

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References

[1] D. G. Thompson, D. V. Arnold, D. G. Long, G. F. Miner, and T. W. Karlinsey. YSAR: A compact, low-cost synthetic aperture radar. In *Proceedings of the 1996 International Geoscience and Remote Sensing Symposium*, pages 1892–1894, Lincoln, Nebraska, May 1996.