YSAR: A Compact, Low-Cost Synthetic Aperture Radar

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Abstract: The Brigham Young University Synthetic Aperture Radar (YSAR) is a compact, inexpensive SAR system which can be flown on a small aircraft. The system has exhibited a resolution of approximately 0.8 m by 0.8 m in test flights in calm conditions. YSAR was used to collect data over archeological sites in Israel. Using a relatively low frequency (2.1GHz), we hope to be able to identify walls or other archeological features to assist in excavation. A large data set of radar and photographic data were collected over sites at Tel Safi, Qumran, Tel Micnah, and the Zippori National Forest in Israel. We show sample images from the archeological data. We are currently working on improved autofocus algorithms for this data and are developing a small, low-cost interferometric SAR system (YINSAR) for operation from a small aircraft.

INTRODUCTION

A Synthetic Aperture Radar (SAR) is an imaging radar which uses signal processing to improve the resolution beyond the limitation of the physical antenna aperture. Typical SAR systems are complex and expensive. The BYU SAR (YSAR) is a relatively inexpensive, lightweight system. The system is designed to be flown in a four or six passenger aircraft at altitudes up to 2000 feet. The system cost and complexity are kept low by using commercially available parts for most of the components, as described in [1]. Initial system tests in calm weather estimated the effective resolution to be about 0.8m by 0.8m.

The system was used to take data over several archaeological sites in Israel to help map the areas for excavation. These areas include Zippori National Forest, Tel Safi, Tel Micnah, and Qumran. These data have slightly worse resolution than the initial tests because of uncorrected aircraft motion. We are currently working on applying autofocus methods to this data.

This paper describes the YSAR system and presents results obtained from the Israel flights. The first section shows the block diagram and briefly describes the system. The next section shows some results from the Israel data. The third section describes current and future work.

SYSTEM DESCRIPTION

The YSAR system is composed of an RF subsystem, a chirp generation subsystem, a digital subsystem, and an antenna subsystem. A block diagram of the system is shown in Fig. 1. The entire system weighs approximately 360 lbs, with over half that coming from a battery-power supply.

The RF subsystem mixes the 100 MHz bandwidth chirp up to 2.1 GHz for transmission and mixes the RF radar return from the antenna to an offset baseband which is sampled by the digital subsystem. The chirp is transmitted and received with double-sideband modulation. Though non-optimum, this avoids the cost associated with single-sideband chirp generation and increases the effective bandwidth of the chirp. The baseband chirp and timing signals are generated by a commercial arbitrary waveform generator, synchronized to the RF local oscillator. The antennas used are custom microstrip patch arrays.

ISRAEL RESULTS

The YSAR system was taken to Israel to collect data over archaeological sites in September 1996. Data was collected using the radar and 35mm cameras in six flights over four sites, from 12 September to 17 September. The sites were in Zippori National Forest, Tel Safi, Tel Micnah, and Qumran. Sample images from two of these sites are shown and described below. Each of the images shown in this section has been averaged to 64 looks in order to show an entire strip on the page. The flight direction is top to bottom, with the radar looking to the left. Each strip is approximately 600m by 3.5km, with pixels about 2.5m by 2.5m. The resolution of the one-look images is

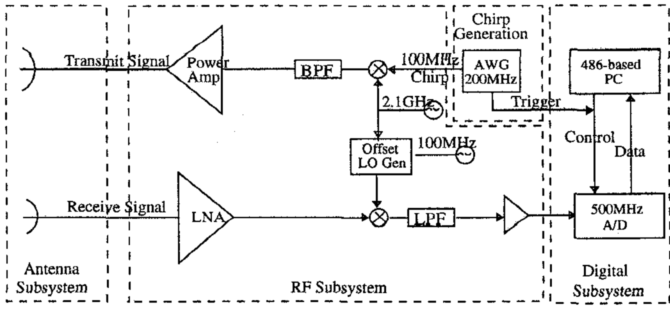

Figure 1: YSAR Block Diagram

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comparable to that obtained in the test flights.

The Zippori National Forest contains a large planted forest, a fortress built by the Crusaders, and ruins believed to be the site of a large center of learning after the fall of Jerusalem in CE 70. The site sits on a large hill and contains many partially excavated ruins. Some of the ruins are largely covered with trees and brush. The biggest challenges to imaging this area are the rocky ground and the hilly topography. A sample image of the area is shown in Fig. 2. The photo-mosaic in Fig. 3 correspond to the area indicated by the box in Fig. 2, which is below the hill of the main site. The main archaeological site is just above the upper right corner of the portion covered by these photographs.

Another image from the Zippori site is shown in Fig. 4. This image covers much of the main site of interest. A set of corner reflectors arranged in a cross can be seen in a field near the start (top of the page) of the image, indicated by the arrow. The 2-foot trihedral corner reflectors are spaced 10m apart. Many rock fences, excavations, buildings, roads, and trees can be seen throughout the image. Analysis of these images is continuing, both for better focusing and for archaeological interpretation.

Tel Safi is believed to be the site of the ancient Philistine city of Gath, home of Goliath as mentioned in the Bible. There is also evidence of other, more recent settlements on the site. The site sits on a small hill (tel) in a large, mostly flat plain. Figure 5 shows an image from Tel Safi. The tel spans the middle portion of the image. Many features can be seen in this portion which were not evident from the ground. A set of 2-foot corner reflectors in an 'L' configuration is indicated by the arrow. Variations in field types can also be seen, and a large wadi is evident near the start of the image.

CURRENT AND FUTURE WORK

We are currently working on and planning several projects to improve the imaging capabilities of the YSAR system. Some of these are described in the following.

Motion compensation is a significant problem in all SAR systems, and more so in the small, low-flying aircraft used for YSAR. The initial system tests were conducted in good weather conditions and at optimum times of the day. We were not able to choose our flight times as well for the flights in Israel, so these images are more corrupted by motion of the aircraft. We are currently adding more motion measurement to the system and working on improved methods of autofocusing. Future YSAR flights will include measurements from a kinematic GPS system which gives both attitude and position. There will also be a set of accelerometers set up to measure linear and rotational motion and to interpolate between the GPS measurements. The accelerometers are based on recent advances in MEMS technology and thus provide good performance while preserving the low cost of the YSAR system.

Autofocus for YSAR is made more complicated than in traditional systems by several factors. Most of the autofocus algorithms currently in the literature are for spotlight SAR, while YSAR is a stripmap system. YSAR covers a much wider range of incidence angles (nadir to 60° in many cases). We are working on modifying autofocus algorithms to apply them to our system.

We are also in the final stages of building a 10 GHz interferometric SAR (YINSAR) which will be operational this summer. We plan to operate both systems together to obtain 10 GHz and 2 GHz images of the same areas.

References

[1] Douglas G. Thompson, David V. Arnold, David G. Long, Gayle F. Miner, and Thomas W. Karlinsey. Ysar: A compact, low-cost synthetic aperture radar. In Proceedings, IGARSS '96, pages 1892–1894, Lincoln, Nebraska, May 1996.

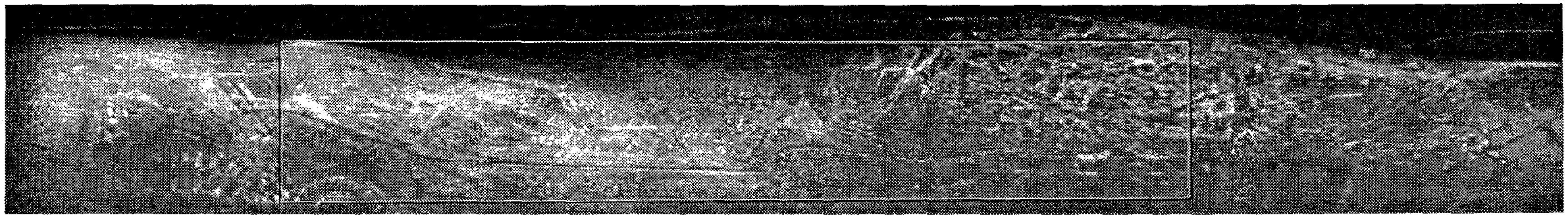

Figure 2. A sample image from the Zippori site. The portion of the image indicated by the box corresponds to the photo-mosaic in Fig. 3

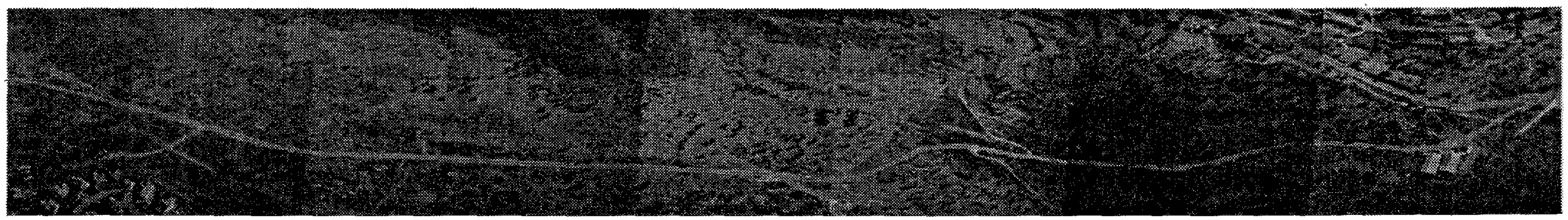

Figure 3. A photo-mosaic of the Zippori site corresponding to the boxed portion of Fig. 1.

Figure 4. An image showing the main Zippori site. A cross of corner reflectors is indicated in a field near the left edge.

Figure 5. An image from the Tel Safi site. An 'L' of corner reflectors is indicated.