THEORETICAL AND PRACTICAL DESIGN CONSIDERATIONS FOR A SMALL, MULTI-BAND SAR: THE SLIMSAR

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1. INTRODUCTION

The SlimSAR is a new advancement in high-performance, small, low-cost, SAR, suitable for operation on small unmanned aircraft systems (UAS). This multi-band SAR was designed by exploiting the techniques and technologies developed for previous systems, resulting in increased capability and flexibility, all in a small package.

UAS are being used more frequently in military, civilian, and scientific applications providing remote-sensing, surveillance, reconnaissance, and environmental monitoring capabilities. Most sensors typically used on small UAS are electro-optic/infrared (EO/IR) instruments, which are limited by obstruction due to clouds, fog, dust, and smoke. On larger platforms these limitations are overcome using synthetic aperture radar (SAR) which provides high-resolution imagery day and night in all weather conditions. In addition, SAR imagery at different frequencies can provide a variety of information about an area. There would be many benefits of operating a multi-frequency SAR on a small UAS, but the large size and weight of typical SAR systems preclude their use.

This paper describes the design of the SlimSAR, a small, multi-band SAR system. We discuss a number of theoretical and practical design considerations and the corresponding performance trade-offs and also presents examples of the operational capabilities of the SlimSAR. In Section 2 we discuss the system design methodology, Section 3 details the design, and Section 4 shows example SAR imagery from the SlimSAR.

2. SYSTEM DESIGN METHODOLOGY

ARTEMIS, Inc. has been supporting SAR programs for over decade with development and manufacturing. Our receivers, exciters, and up-converters are a part of Global Hawk, U-2, and ASTOR.

Recent experimental programs include the UAVSAR and GLISTEN with Jet Propulsion Laboratory, the NuSAR [1] with the Naval Research Laboratory (NRL) and Space Dynamics Laboratory (SDL), and in association with Brigham Young University (BYU), the MicroASAR [2].

The SlimSAR was designed using an innovative methodology [3, 4]. The goal is to find the quickest path from system requirements specification to deployment of a successful solution. The SlimSAR design is based on the tested SAR systems, the MicroASAR and NuSAR. The existing designs were exploited to keep much of the design heritage while best meeting the requirements for the SlimSAR system. The risks associated with new, untested technologies are thus minimized.

Basing the design on an existing SAR system provided benefits for the integration and system testing process. The MicroASAR was operating during the SlimSAR development period on a small, manned aircraft used as a UAS surrogate. Using the microASAR data from these flights, the data collection, handling, and processing methods were refined then used with very little modification for SlimSAR. The system was therefore ready for initial flight testing as soon as the hardware was completed. Immediate flight testing on the test bed aircraft reveals necessary changes in the SAR system, the processing algorithms, and other supporting systems. The SlimSAR went from preliminary design to flight testing in nine months.

3. THE SYSTEM DESIGN OF THE SLIMSAR

The SlimSAR is designed as a compact pod-mount unit consisting of the radar, a motion measurement system, GPS, miniature CDL, conformal wide-beam L-band antenna and a gimbaled X-band antenna. This entire system weighs less than 20 lbs and consumes less than 150 Watts.

3.1. LFM-CW SAR Signal

The use of a linear frequency-modulated continuous-wave (LFM-CW) signal facilitates compact design, allowing us to achieve a high signal-to-noise ratio while transmitting with less peak power.

For LFM-CW SAR, the received signal is mixed with the transmit signal, resulting the difference between the signal frequencies. Near range targets have a lower frequency than far range targets. The bandwidth of this signal is much less than the transmit signal bandwidth, thus the digital sampling requirements are relaxed.

Transmitting with less power and sampling the data at a slower rate can be done with hardware that is smaller, lighter, and consumes less power than traditional pulsed systems. The disadvantages are that the transmit and receive channels require separate antennas and feed-through between the antennas must be controlled.

3.2. Delayed Mix-Down Chirp

The system has two direct digital synthesizers (DDS) which generate identical SAR signals, with one delayed by the time of flight to the closest range of the desired imaging area. When the received signal is mixed with this second chirp, the bandwidth is reduced, lowering our sampling requirements.

In LFM-CW SAR, the swath width is usually very limited, but with our delayed mixdown chirp we can increase the width of the imaged area. This swath width is constrained by a number of inter-related factors: 1. The width of the intermediate frequency filter, 2. The chirp rate and chirp bandwidth, 3. The pulse repetition frequency and antenna beamwidth, 4. The platform altitude (AGL), 5. The maximum data rate, and 6. The mix-down chirp delay

3.3. Overall System Design Walk-Through

The core of the system is the L-band portion. An FPGA controls the variable system parameters making sure the DDS's, the ADC, and the data storage are all working together. The DDS's generate the SAR signals which are up-converted to L-band (at different frequencies). The signal is either transmitted through the antennas or up-converted to X-band (or any other desired band) through a block converter.

The signal is received, amplified, and in the case of the X-band signal, down-converted to L-band. The signal is mixed with the delayed second chirp, offset in frequency, which de-chirps the signal at an intermediate frequency. A SAW band-pass filter with large out-of-band rejection removes the antenna feed-through and signal returns from outside the target area. The reduced bandwidth signal is mixed-down and digitized. The digital signal is streamed via Ethernet to on-board storage, the tactical data-link, and/or and on-board processor. Range-Doppler, frequency-scaling, and backprojection algorithms have been developed for processing the data. The backprojection algorithm allows for non-linear flight paths (i.e. circular).

3.4. System Specifications

The SlimSAR is designed to support a contiguous signal bandwidth of up to 660 MHz. A configuration that we have FCC permission to use has a center frequency of 1257.5 MHz with an 85 MHz bandwidth. The L-band transmitter is capable of alternating pulses between horizontal and vertical polarization for polarimetric operation. The addition of block converters allow for additional frequencies. Initially the SlimSAR has been designed with an block converter which allows transmission over two separate bandwidths at X-band.

The built in solid-state power amplifier is designed to output 4 Watts continuous peak power. This power level is sufficient for an altitude of 5000-8000 feet above ground level (AGL). It is possible to add an external power amplifier in order to obtain a better SNR at higher altitudes.

3.5. Supporting Subcomponents

There are several important subsystems which support the generation and exploitation of high-quality SAR imagery. The SlimSAR includes a motion measurement system, and a gimbal for high-frequency antennas. It also includes a gigabit Ethernet interface which allows for the integration of a tactical data-link for transferring the raw data to a ground station where it can be processed in near real time.

3.6. System Performance Trade-offs and Flexibility

Every radar system has inherent performance tradeoffs, and SlimSAR is no exception. The unique design of the SlimSAR, however, makes it very flexible. By simply adjusting some of its operational parameters, the SlimSAR can be made to operate in a wide variety of imaging situations.

4. SAMPLE SAR IMAGERY

The SlimSAR has been flown in a variety of locations. This paper includes sample imagery from the SlimSAR and the microASAR collected near Everett, WA (see Fig. 1).

5. CONCLUSION

The advantages of a strong design heritage combined with rapid testing and integration are evident in the design of the SlimSAR. The quick schedule of going from initial concept designs in October 2008 to flight testing the week of 15 June 2009 has demonstrated the utility of our design methodology. The flight tests are aimed at proving and improving the SlimSAR and readying the system for integration onto a small UAS. The flexible design allows for future modifications such as alternative frequencies (currently under development are UHF and Ku-band frequencies), higher bandwidths, and specific applications such as GMTI, interferometry, littoral and maritime modes, and polarimetry.

6. REFERENCES

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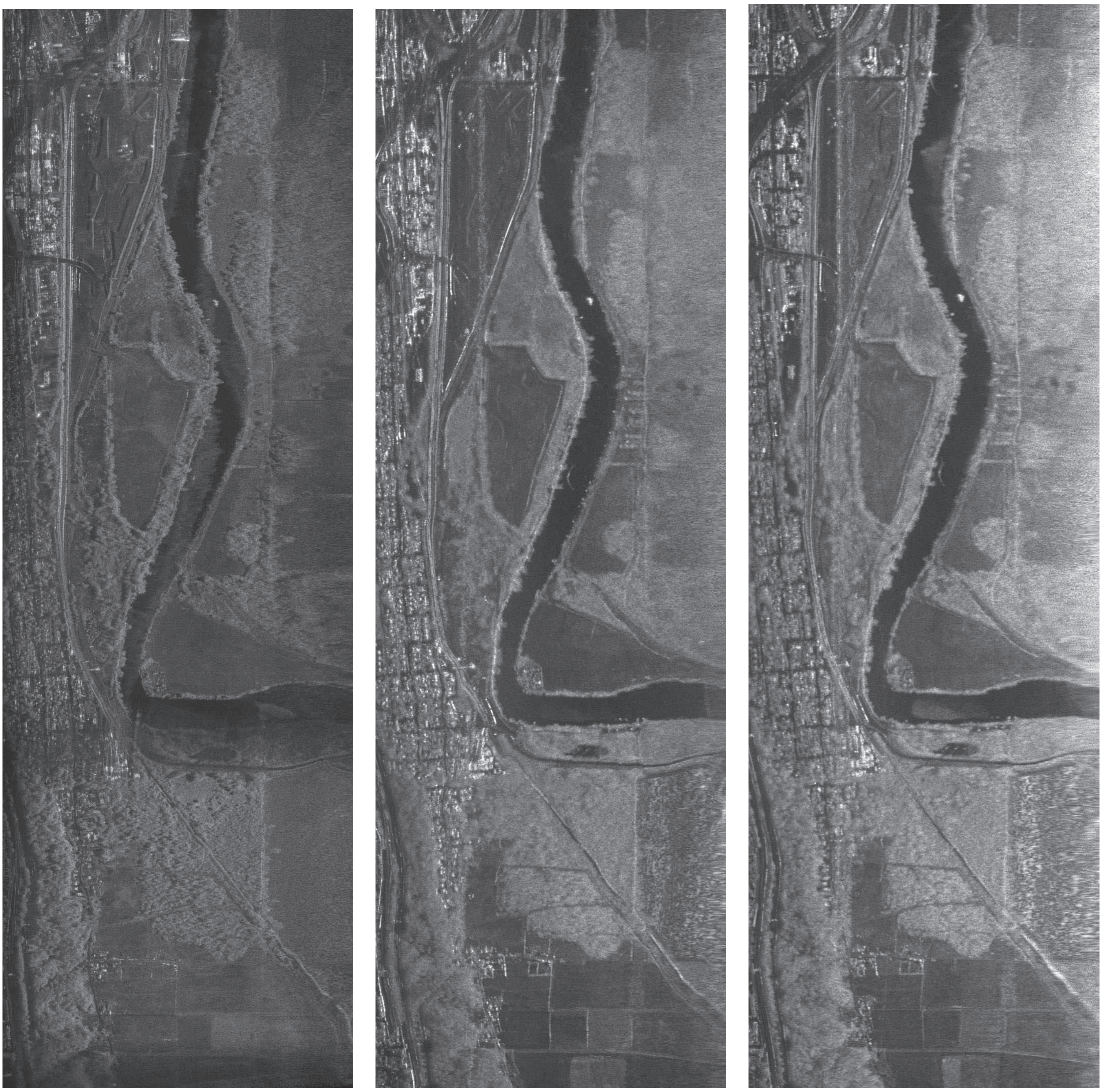

Fig. 1. Simultaneously collected SAR images of an area south of Everett, Washington. The leftmost image is a C-band microASAR image with a range resolution of 88 cm. The center image is an L-band HH-pol SlimSAR image with the rightmost being L-band VV-pol SlimSAR. The SlimSAR L-band images have a range resolution of 1.76 m, corresponding to the 85 MHz bandwidth.

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