A Small, Manned Aircraft as a Testbed for Radar Sensor Development

Matthew C. Edwards[a], Evan C. Zaugg,[a], David G. Long[a], Richard Christiansen[a] and Alex Margulis[b]

[a]Brigham Young University, 459 CB, Provo, UT, USA;
[b]Artemis, Inc., 36 Central Ave, Hauppauge, NY, USA

ABSTRACT

The flight testing phase is vital in the development of an airborne SAR system, but can be time consuming and expensive, especially for UAS based systems. As part of a SAR design methodology, we are using a small, manned aircraft as a surrogate for UASs and other platforms. Prototypes of new systems can be easily installed on the testbed in order to quickly and inexpensively obtain sensor and motion data. These data can be used to aid in system-specific algorithm development, as well as further refinement of the system hardware as necessary.

Keywords: Synthetic aperture radar, SAR, unmanned aircraft, UAS, design, testing

1. INTRODUCTION

The design and testing of a successful synthetic aperture radar (SAR) system is a long and complicated process. Historically, SAR systems have been deployed mainly on orbiting spaceborne platforms and large, high-altitude airborne platforms. It has often been necessary to spend many years and a great deal of money designing a SAR system which performs optimally on the intended platform. In some cases, the platform itself may be designed for the specific purpose of carrying the SAR system, while in others the platform may be suboptimal.

In recent years, unmanned aircraft systems (UASs) have become increasingly useful for tasks such as airborne reconnaissance and surveillance. SAR systems can create images day or night, through dust or clouds, and in some cases are able to penetrate foliage or dry soil. These capabilities compliment visible and infrared sensors to provide a more complete view of an observed scene. The recent profusion of UASs has introduced a need for rapid development of small, lightweight SAR systems which can be deployed successfully on a variety of small platforms. The testing of these types of systems is complicated by the many restrictions placed on the deployment of UASs. For this reason, it is generally not practical to deploy a new system on an unmanned platform until it has been completely designed, fabricated and integrated.

This paper describes a simple SAR design methodology which uses a small, manned aircraft as a surrogate for UAS and other small platforms. No attempt is made to describe all the intricacies of SAR system design, but rather to outline a method by which SAR systems may be designed more quickly and effectively. The process outlined here has been successfully utilized in the design and testing of a small SAR system called microASAR.[1] This paper also outlines the use of the method by Artemis, Inc. in the design of a new system called SlimSAR. Selected results from the Artemis testbed are presented.

2. OVERVIEW OF THE DESIGN PROCESS

This section lists the major points of the design and testing process.

1. We begin with a basic SAR system which can be modified to meet given requirements. This can be used as a test system. Although it may be useful to have the capability of operating in more than one frequency band, it is most useful to operate in a band with minimal restrictions. The test system need not be designed to meet any specific criteria, but it is important to know its capabilities and limitations.

2. An airborne testbed is required. Because this methodology is being applied specifically to UAS-based SAR systems, the testbed ought to be relatively small and lightweight. Such aircraft are susceptible to non-ideal motion which is somewhat similar to that which an unmanned aircraft would encounter during flight. The test system is installed on the testbed aircraft in such a configuration that frequent operation is relatively painless.

3. The testbed aircraft is outfitted with a precision motion measurement system. This motion system consists of a GPS receiver, and an inertial measurement unit (IMU). The IMU contains gyroscopes and accelerometers which are used calculate the heading and spatial position of the aircraft. When combined with the GPS data, an accurate history of the position, heading and velocity of the aircraft can be derived.

   Different SAR systems require varying degrees of accuracy from the navigation solutions produced by the motion measurement system. For instance, a high resolution system which operates at an extremely high frequency requires very accurate navigation solutions because a small movement in the aircraft may result in an error which is on the order of several wavelengths and is spread across multiple pixels. The testbed should be outfitted with a high quality motion measurement system so that the data which is collected for test purposes is sure to be sufficient for precision image formation. Simulations of UAS motion can be derived by appropriately degrading the precision motion data. It is also desirable to configure the testbed so that the data from one or more GPS/IMU systems can be aligned with the data from multiple SAR systems. This increases the flexibility of the test environment by allowing new systems to be tested before they have been specifically integrated with a particular motion measurement system.

4. The testbed, containing test SAR system(s) and motion measurement system(s) is flown as often as is necessary to enable the test team to consistently create high quality SAR image products. Algorithms are developed for data processing and motion compensation using the data gathered during test flights.

5. New SAR systems which address specific problems are developed by noting what must be changed in the existing test system to meet the new specifications.

6. Based on (5) the new SAR system design is developed based on the existing system design. Key functional system elements are retained as much as possible. New system concepts are tested using the existing system. Necessary changes to the processing algorithms are anticipated based on the known design changes.

7. As soon as working prototype hardware for the new system is completed, it is installed on the testbed platform for testing. Since the environment on a small manned aircraft is not as constrained as that of a UAV, this may be done before the system is in its final configuration. The testbed itself provides motion measurement and data storage systems so that the SAR may be tested before these have been integrated. The algorithms developed with the earlier test system are now finalized so that they produce good results with the new system.

8. When the new system is working well on the testbed aircraft, the necessary time, effort and money is expended to finalize design details and test the system on the intended UAS platform. It is anticipated that any necessary changes at this point will be minor, since the SAR system has already been demonstrated to work properly on the testbed. As a result, time spent testing and integrating the system on its intended platform is decreased.

9. Once a new SAR system has been developed, a copy of it can be kept for use on the testbed. In this way, future SAR systems may need only a few changes from an existing, tested system in order to meet given requirements.

Understandably, the most difficult part of implementing this design and testing process is obtaining the aircraft and initial SAR system to begin with. However, once that initial hurdle is cleared, the process becomes self-perpetuating as previous systems are used as archetypes for the rapid design of new systems with different capabilities.

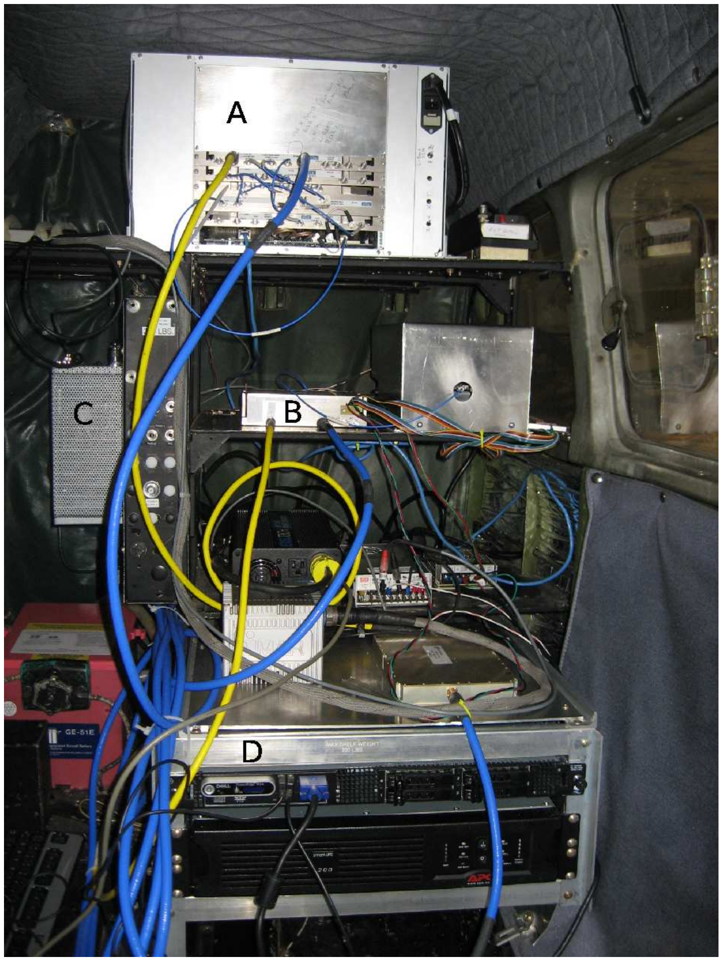

Figure 1. Equipment setup inside testbed aircraft. Labelled are: (A) pulsed SAR system, (B) CW microASAR system, (C) BYU Motron, and (D) computer for data storage and processing. The configuration shown can be rearranged to accommodate new systems for testing.

3. SAMPLE TESTBED SYSTEM

Artemis, Inc. has implemented the design methodology outlined above in order to more quickly and efficiently design UAS-based SAR systems. The following section describes this particular implementation as an illustration of how the process may be used.

3.1 SAR Systems Used for Testing

Two fully functioning SAR systems are currently being operated on the Artemis testbed. The first is a low power, pulsed system. In its current configuration, it has a peak transmit power of 25 W and is designed to operate at 2500-6000 ft above ground level (AGL). The system operates at L-band with a variable bandwidth of 500 MHz maximum, but the addition of a block up/down converter enables operation in other frequency bands as well. It is currently outfitted with a block converter which allows X-band operation. The second system is a continuous wave (CW) SAR system called microASAR. Because a CW system is constantly transmitting and receiving, it is capable of maintaining a high SNR while transmitting much less peak power than a comparable pulsed system. The microASAR is configured to transmit 1 W of peak power and operates in the range of 1000-3000 ft AGL. It operates at C-band with a variable bandwidth of 200 MHz maximum. These two systems combine to give a reasonably wide range of possible scenarios in which test data may be obtained.

Figure 2. The O-2 Skymaster, dubbed “Surf Angel”, which is being used as an airborne SAR testbed. With the wings mounted on top of the fuselage, the pilot and radar operator can easily observe the ground below. Radar antennas are mounted beneath the aircraft and angled so that they radiate toward the passenger side.

3.2 Aircraft Used as Testbed

A Cessna O-2 Skymaster (shown in Fig. 2) is being used as the Artemis testbed platform. The aircraft is a twin-engine piston powered aircraft, with one engine in the nose of the aircraft and a second engine in the rear of the fuselage. The unconventional engine placement enables the wings to be built atop the fuselage so that they do not block observation of the ground beneath the aircraft. The plane accommodates a pilot and a radar operator, and the rear of the cabin is outfitted with a rack on which different types of radar equipment may be securely mounted as shown in Fig. 1.

The O-2 Skymaster has a wingspan of 38 ft, a length from tip-to-tail of 30 ft and a height of 9.17 ft. When empty, the aircraft weighs approximately 2,800 lb. The service ceiling is 18,000 ft and the maximum airspeed is 175 knots (approx. 200 mph). In contrast, a mid-sized tier II unmanned aircraft generally has dimensions that are less than half those of the O-2 Skymaster, while weighing less than 500 lbs fully-loaded. The difference in weight makes the O-2 Skymaster more stable in wind and turbulent air than a lighter UAS — a fact which must be taken into account when preparing algorithms for motion compensation in the SAR data.

The testbed aircraft is extremely useful because, unlike an unmanned aircraft, it may be flown on short notice and without special authorization. It is therefore a reasonable surrogate for unmanned platforms being targeted for SAR deployment, even though its motion doesn’t exactly match that of a UAS.

3.3 Motion Measurement System

The motion measurement system installed on the Artemis testbed consists of a GPS, an IMU, and a small embedded computer system which has been labelled the “Motron”. The Motron, which was developed at Brigham Young University, interfaces with and controls the Novatel GPS/IMU unit. Navigation solutions and raw GPS/IMU data is recorded by the Motron at a rate of 50 updates per second. This data is stored by the Motron unit, independent of any of the SAR systems on the aircraft. A serial interface enables the different radar systems to store synchronized time stamps in the radar data so that the navigation solutions may be aligned with data from any of the test radars during post-flight processing. Although the Novatel GPS/IMU and BYU Motron are too heavy and bulky to be effectively mounted on most unmanned aircraft, they provide the raw motion data necessary to develop a system which meets size and weight requirements as well as accuracy requirements.

3.4 Central Data Collection System

When deploying a SAR system on a UAS, it is generally necessary to include a wireless data link in order to transfer the SAR data to a ground-based control station in real time. Although the data link is an important component to test, it can be an unwanted complication during early testing. In order to ensure that all test

Figure 3. Stripmap SAR image of a portion of Brigham City, UT processed from data gathered using microASAR on the Surf Angel testbed. The suburban area is interrupted by a gravel pit in the center of the image which is much less reflective.

data gathered on the testbed is stored for later analysis, the aircraft has been fitted with a rack-mount computer which acts as a data storage and processing system. The computer has been outfitted with 320 GB of solid-state storage, which is more robust than rotating disks in the high vibration environment of an aircraft. Two gigabit ethernet controllers allow simultaneous recording of data from two separate SAR systems as well as providing a means of controlling the functions of the SAR systems. The computer system also has enough memory and processing power so that it may be used to test real-time data compression and processing algorithms during flight.

4. RESULTS FROM ARTEMIS TESTBED

The Artemis testbed has been operating successfully since October 2008. In this time, we have accomplished several key goals that were set for the project. These include:

Successful flights of both the pulsed SAR and CW microASAR Raw SAR data has been collected and processed using both test systems. A number of flights over different terrains and targets provides validation of theoretical system capabilities. Processing algorithms have been developed to compress raw SAR data into stripmap images. Characteristics specific to the test systems, such as feedthrough between antennas for the continuous wave microASAR, have been observed and accounted for in processing. Figure 3 displays a segment of an image formed using the microASAR.

Use of collected motion data to improve image processing The motion data collected independently by the Motron system has been aligned with recorded SAR data in order to improve the quality of processed images. Figure 4 displays a segment of microASAR data processed with and without motion compensation in order to illustrate the potential for image improvement.

Calculation of navigation solutions from raw GPS/IMU data Software which calculates navigation solutions from the raw output of the GPS and IMU has been developed. The navigation solutions computed by the Novatel unit provide a good benchmark against which to measure the accuracy of our own solutions.

5. A PRACTICAL IMPLEMENTATION OF THE TESTBED DESIGN METHODOLOGY

The Artemis testbed described in Section 3 is being actively used to develop new SAR systems. The latest project requirement is a system which:

- is small and lightweight enough to operate on a tier II UAS,

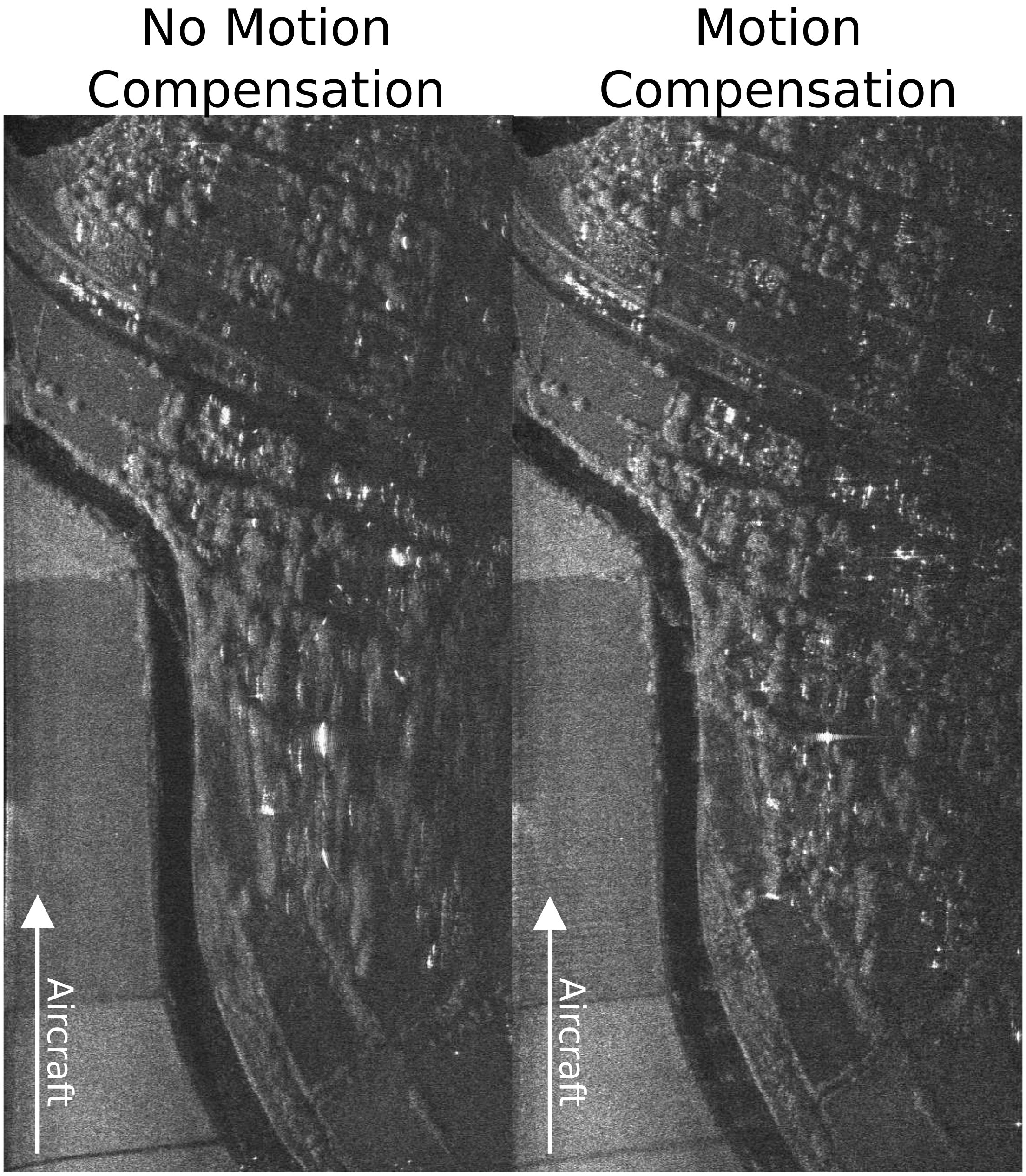

Figure 4. Side-by-side comparison of microASAR data processed with and without motion compensation. The image on the left has been processed with the assumption that the aircraft travelled in a straight line at a constant velocity. The image on the right was processed using information about the velocity and attitude of the plane which was collected during flight. The improvement is particularly noticeable near the bottom of the image where trees and bright targets are smeared in the left image, but tightly focused in the right image.

- can operate in the 5000-8000 ft AGL range,
- can operate in L- and/or X-band at high resolution,
- produces raw data at a low enough rate to make a real-time data link viable,
- can be designed, built, and deployed more quickly than traditional design methods..

Following the outline in Section 2, we focus only on the changes that must be made to existing test systems in order to make them meet the given requirements. The existing pulsed SAR operates in the required bands and at the required altitude. In its current incarnation however, the system is too large, too heavy, and consumes too much power to be deployed on the target platform. Additionally, it produces raw SAR data at an extremely high rate. The microASAR has the requisite form-factor, and an analog dechirp stage in the design results in low data rates. Unfortunately, the microASAR's particular implementation of CW SAR with analog dechirp limits the maximum altitude to less than 5000 ft AGL and produces extremely narrow swaths at such high altitudes.

The choices for the new system, then, are: 1) a pulsed system which has been redesigned to be smaller, lighter, and consume less power; 2) a CW system like microASAR which is capable of operating at higher altitudes and at a higher resolution; 3) a completely new system designed from the ground up to meet the given requirements. Option two was deemed most likely to succeed in a short time frame. Thus, a new system, named SlimSAR, is being developed which is an extension of the microASAR design. The transmit frequency has been changed so that the main unit generates signals at L-band, while an external block up/down converter can be added for operation at other frequencies such as X-band. The analog dechirp scheme has been modified to a delayed analog dechirp which overcomes the altitude and swath limitations of the microASAR, and the transmit power has been boosted from 1 W to 4 W in order to improve the SNR at higher altitudes.

Because the SlimSAR is so similar to the existing microASAR, the image formation and motion compensation algorithms are nearly identical. Work currently being done to improve the quality of microASAR imagery will translate directly to the SlimSAR. Therefore, even though the SlimSAR system is still under development at the writing of this document, many of the most important system concepts have already been tested and validated. These include the viability of CW SAR for the desired application, the development of processing and motion compensation algorithms, and the ability to produce accurate navigation solutions from raw GPS/IMU data. Work on improving microASAR imagery can be continued until the SlimSAR RF hardware is complete. Once the RF portion is complete, the system can be immediately installed in the testbed aircraft using the existing motion measurement and data storage subsystems. Adjustments to the system can be accomplished before finalizing a rugged, self-contained unit suitable for operation on a UAS.

6. CONCLUSION

In this paper we breifly described a process which uses a small, manned aircraft as a UAS surrogate in the design and testing of new SAR systems. The proposed method uses a manned aircraft to test small SAR systems which can be deployed on unmanned aircraft as is, or serve as the base of a modified system which meets specific requirements. The manned aircraft is fitted with supporting hardware such as motion measurement and data storage hardware so that new designs may be tested as quickly as possible.

The proposed methodology is being used by Artemis, Inc. to develop a system called SlimSAR which is based on an existing Artemis CW SAR system called microASAR. While SlimSAR is under development, data gathered from microASAR and the motion measurement system mounted on the testbed are used to develop processing algorithms and refine the SlimSAR design. In this way, many aspects of the design are verified while the hardware is being developed and the final testing process is simplified significantly.

REFERENCES

[1] Edwards, M. C., *Design of a Continuous-Wave Synthetic Aperture Radar System with Analog Dechirp*, Master's Thesis, Brigham Young University (April 2009).