DEVELOPMENT OF EMBEDDED SAR PROCESSING MODULE FOR UAV AND MICROSATELLITE APPLICATIONS

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ABSTRACT

The design and development of Synthetic Aperture Radar (SAR) is one of the focused research areas in Malaysia since early 2000s. The main objective of this research is to develop an all-weather instrument for earth resource monitoring. As per today, three SAR sensors have been developed, each operating at L-band (1.27 GHz), S-band (3.125 GHz) and C-band (5.3 GHz), respectively. Although each of these sensors has its own dedicated radio frequency (RF) subsystem, their digital SAR processing module is common across all operating frequencies. This paper presents the design and development of the embedded SAR processing module, which is suitable to be mounted on small UAV and/or micro-satellite platforms. Its unique features include compact size, light weight, and equipped with onboard processing capabilities.

Keywords: Synthetic Aperture Radar (SAR), embedded processor, unmanned aerial vehicle (UAV), micro-satellite

INTRODUCTION

An unmanned aerial vehicle (UAV) is typically used in surveillance and reconnaissance missions with onboard remote sensing instruments such as electro-optical (EO) sensors, infrared (IR) sensors and synthetic aperture radars (SARs). Recently, there is an increase popularity of UAV-based system as compared to conventional aircraft [1]-[9]. This is mainly due to the fact that there is no risk of losing human life in UAV flight mission, and the size and the cost of a UAV system are significantly less than a manned aircraft with the same performance. In terms of remote sensing applications, UAV-SAR has great potential due to its all-day, all-weather capabilities. In many cases, UAV platform can also serve as a testbed for micro-satellite SAR's performance verifications.

The major challenge in both UAV-based and micro-satellite SAR design is due to its limited payload weight, size, and onboard power supply. Typically, the allowable sensor payload is less than 50 kg in weight, less than 1 ft^3 in dimension, and it has to be operated at less than 200 W of power supply. As a result, the onboard SAR processing module must be compact in size, light weight, low power consumption, and at the same time possess fast processing capabilities for real-time implementation. This has led to the use of high speed dedicated chipset, such as the digital signal processor (DSP) or the field-programmable gate array (FPGA), in an embedded SAR processor.

On the other hand, the design of a general-purpose computer-based SAR processor may require less development cycle as compared to the DSP or the FPGA-based system, since computer-related hardware interfaces (such as USB interfacing, PCI express bus interfacing, etc.) and software tools (such as Visual Studio, Matlab, etc.) are commonly available. The main drawback of a general-purpose computer system is that it is not optimized for time-critical tasks. Nevertheless, with the recent advancement of multi-core processor systems, it is possible to implement an embedded real-time SAR processor using a high performance computer (HPC). A hybird architecture is also possible whereby non time-critical tasks are handled by the HPC while application-specific tasks (such as chirp signal generation, SAR timing control unit, high-speed data acquisition unit, and SAR pre-processing) can be seamlessly integrated using FPGAs.

DESIGN SPECIFICATIONS

Table 1 compares the design specifications of an onboard SAR processing module targeted for a typical low altitude UAV and a micro-satellite at high earth orbit (HEO). As far as the SAR processing is concerned, it is observed that most of the system level requirements are similar. The variation in terms of transmitted pulse width and PRF can easily be accommodated by using a variable timing control unit. In this work, a generic SAR processing module has been designed based on the UAV's specifications. It can be reconfigured for micro-satellite SAR operation with slight modifications in timing and control settings.

Table 1. Design Specifications of SAR Processing Module

Design Parameter	**UAV**	**Micro-satellite**
Platform Height	300 – 1000 m	>400 km
Incident angle	30°	30°
Slant Range Resolution	1.5 m	1.875 m
Transmit Pulse Width	0.5 - 5 μs	10 μs
Transmit Bandwidth	100 MHz	80 MHz
Pulse Repetition Frequency (PRF)	500 – 1000 Hz	1000 – 4000 Hz
DAC Resolution	14-bit	14-bit
DAC Sampling Rate (per channel)	125 MSPS	125 MSPS
Number of DAC channel	2	2
ADC Resolution	12-bit	12-bit
Number of ADC channel	2	2
ADC Sampling Rate (per channel)	125 MHz	125 MHz
Overall dimension	< 0.5 ft^3	< 0.5 ft^3
Overall weight	< 10 kg	< 10 kg

DEVELOPMENT OF THE EMBEDDED SAR PROCESSING MODULE

The functional block diagram of the proposed embedded SAR processing (ESP) module is shown in Figure 1. It consists of a custom-designed FPGA, a high speed data acquisition unit (DAQ) and a high performance computer (HPC). The function of the FPGA is to act as a chirp signal generator and a timing control unit [10]. The baseband chirp signal will be up-converted at RF transceiver and transmitted via a SAR antenna. The radar returns will be down-converted and digitized using a high speed 12-bits dual-channel ADC (analog-to-digital converter). The HPC is a duo-core processor, acting as the SAR raw data recording and processing unit. The stored raw data will be further processed onboard to produce SAR images.

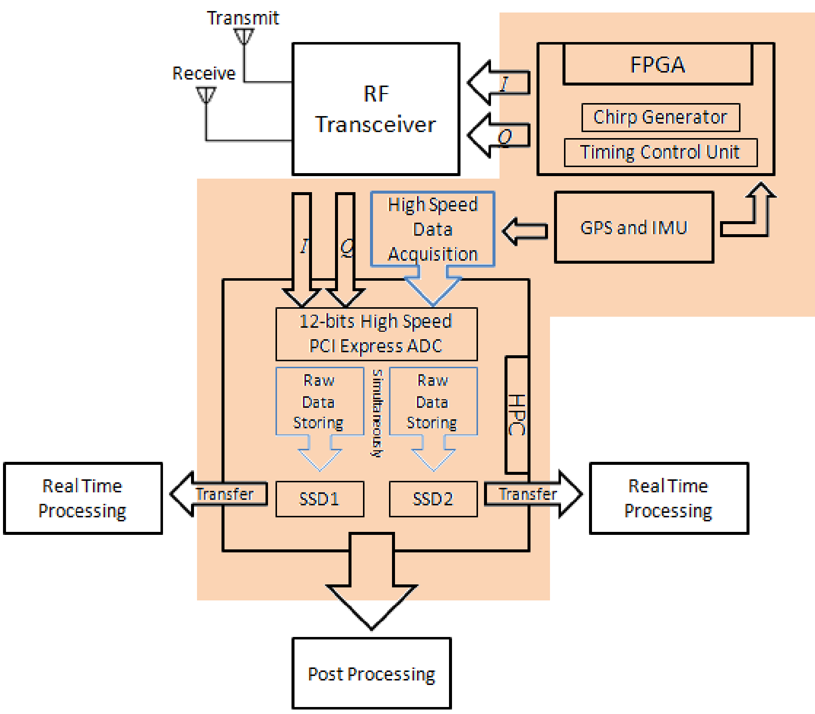


Figure 1. Functional Block Diagram of the Embedded SAR Processor

Real-time implementation is a challenging task in SAR processing. The challenge lies in the fact that a huge amount of data is to be simultaneously recorded and processed within a limited time frame. In this work, hybrid architecture is employed to achieve real-time SAR data recording and processing through the use of FPGA and HPC, as shown in Figure 2. A software selectable SAR data recording ID is used to determine which solid-state drive (SSD) is currently being enabled for data storage. Once the raw data file size reaches the preset limit, the system will switch to the other SSD for data recording, and continue to process the raw data in the first SSD. This approach allows simultaneous data recording and processing through the realization of a single HPC with at least a duo-core processor and two SSDs [11].

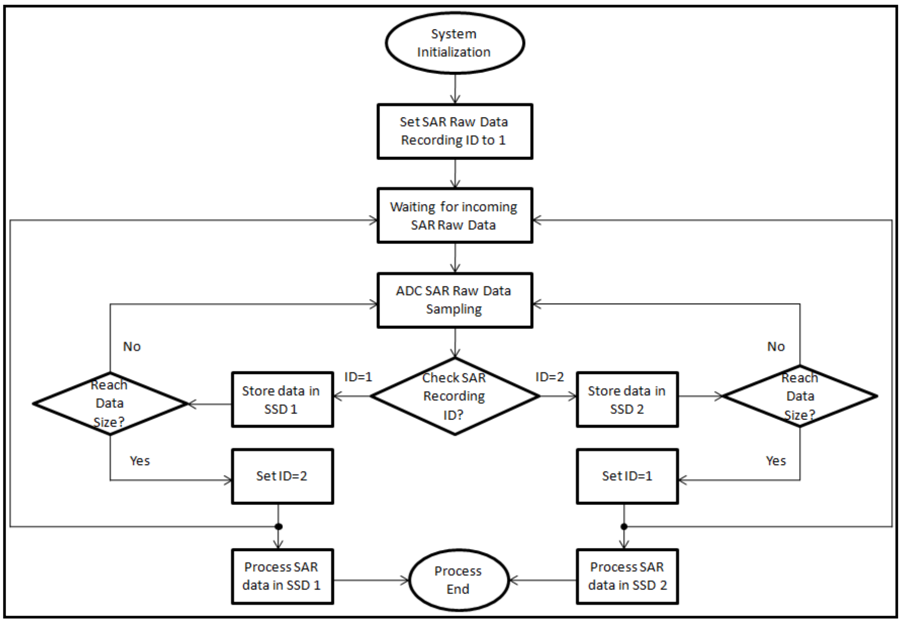
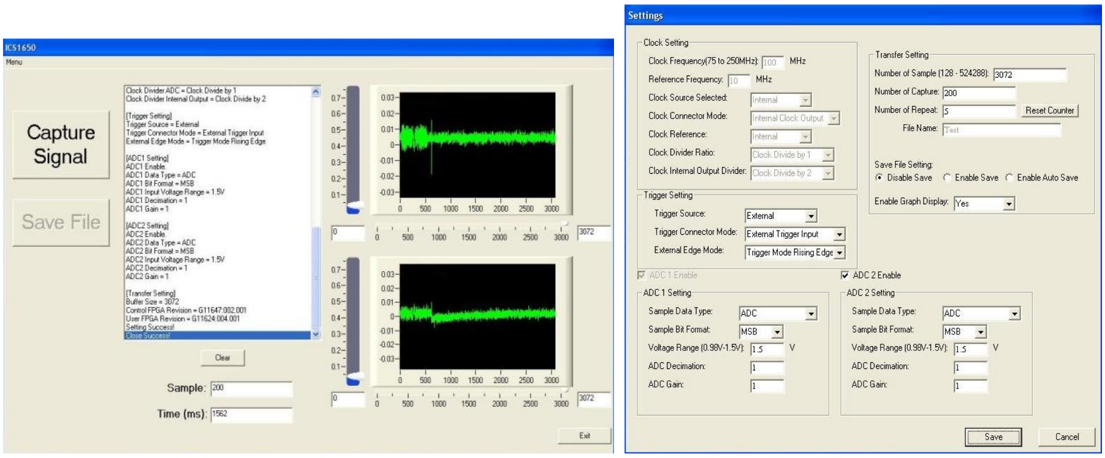


Figure 2. Flow Chart of Real-Time SAR Data Recording and Processing

Figure 3 shows the hardware prototype of the ESP module. A custom-made chassis has been constructed by using aluminium. All the interfacing connectors to external modules are placed at the front panel for ease of access and control. The overall size of the ESP is 270 mm (L) × 240 mm (W) × 140 mm (H) (<0.5 ft^3) with total weight of approximately 3.5 kg.


Figure 3. Hardware Prototype of the Embedded SAR Processing Module

A graphical user interface (GUI) has been developed for real-time data acquisition purposes. Figure 4 shows the screenshot of the GUI. It allows the user to configure the design parameters (such as ADC clock rate, sample size, data format, etc.), with real-time displays of the raw data captured.



(a) (b)

Figure 4. Screenshot of the ESP GUI (a) Main Screen and (b) Setting Screen

SYSTEM INTEGRATION AND PRELIMINARY UAV FLIGHT TEST

In order to perform preliminary tests, the embedded SAR processing module is integrated with a C-band RF transceiver module. The first test is to perform a truck-mounted SAR imaging experiment at an open field. Figure 5 shows the SAR antenna is mounted on top of a land vehicle and it travels along a straight road. The SAR antenna is pointing at an open area perpendicular to the direction of the travel path. As shown in Figure 6, four trihedral corner reflectors are placed as point targets. Figure 7 presents the processed SAR image with four strong targets appeared in the scene.

The second experiment is to perform a UAV flight test by mounting the SAR system onto a small UAV. The flight mission's test site is at Mersing, Johor, Malaysia. Figure 8 shows some of the preliminary SAR images obtained during the flight test.

Figure 5. Ground-based Truck-Mounted SAR Imaging Experiment

Figure 6. Test Site with Four Trihedral Corner Reflectors as Radar Targets

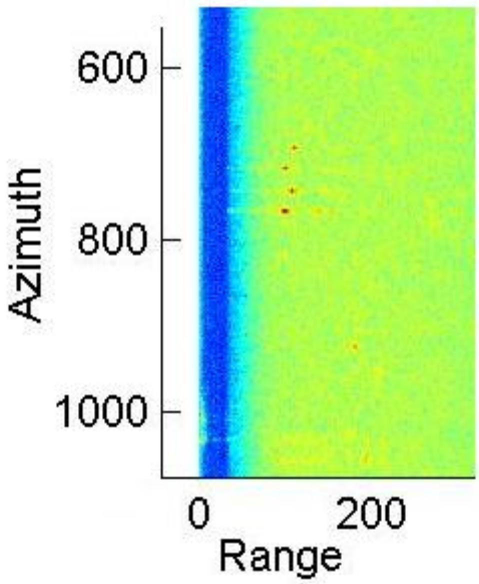


Figure 7. SAR Image of Point Target Returns

CONCLUSION

A compact, miniaturized embedded SAR processing module has been designed and developed. This embedded SAR processing module has overall dimension of less than 0.5 ft^3 and total weight of 3.5 kg, which is suitable to be mounted onto a small UAV for timely remote sensing operation. A series of field experiments has been conducted to verify the performance of the embedded SAR processing module. In near future, the ESP will be upgraded with space-compliance components for micro-satellite mission.

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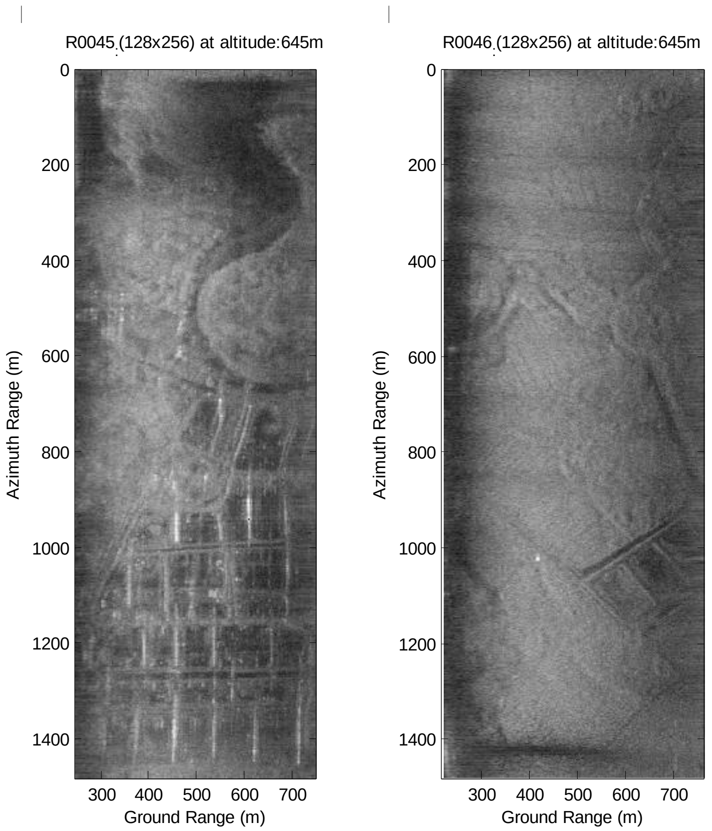

Figure 8. Sample SAR Images Obtained During UAV Flight Mission

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