Synthetic Aperture Radar Calibration and Field Experiment Setup

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Abstract

In 2002, the MASAR (Malaysian Airborne Synthetic Aperture Radar) project was initiated at Multimedia University (MMU), in collaboration with the Malaysian Centre for Remote Sensing (MACRES). The main objective of this project is to construct an instrument for earth resource monitoring in Malaysia. The proposed SAR system is a C-band, single polarization, linear frequency modulation radar. Before the flight campaign, preliminary testing and calibration were conducted to verify the functionality of the MASAR transmitter and receiver subsystems. The field experiment provides two-dimensional image resulting from range and cross range detection. Point target calibration technique is utilized for external calibration. In this paper, the field experiment setup, calibration of MASAR subsystems, radar hardware system as well as the Range-Doppler processing algorithm are presented. Both range detection and radar cross section (RCS) measurements capability are verified in the field experiments.

1. Introduction

Radar has been used for military and commercial purposes for a long time in a wide variety of applications such as imaging, guidance, remote sensing and global positioning [1]. The recent development in Synthetic Aperture Radar (SAR) technology has made possible a much higher resolution to be achieved using a small antenna. The use of SAR for remote sensing is particularly suited for tropical country such as Malaysia. The MASAR project started in 2002, after preparatory studies in the previous years [2]. The proposed system is an airborne, single polarization, linear FM radar operating at C-band. This SAR system is designed to operate at moderate altitudes with low transmit power and small swath width in order to optimize the development cost and operating cost. Preliminary testing and calibration were carried out to verify the functionality of the SAR transmitter and receiver subsystems. Based on the measurement results reported in numerous literatures, it is found that the typical value of scattering coefficients for various categories of terrain falls in the range from 0dB to –30dB [3]. Therefore, a wide dynamic range (>30dB) is needed to accommodate the measurement of various types of terrain.

2. Radar Hardware System

Figure 1 shows the functional block diagram of the MASAR system that will be implemented. The whole system design [4] is based on a low intermediate frequency (IF). Basically it consists of a microstrip antenna, a radar electronics subsystem and a data acquisition system.

For the radar electronics subsystem, an arbitrary waveform generator (AWG) is used to generate the required linear frequency modulation (FM) chirp signal. The microwave source of the MASAR is a 5.3GHz dielectric resonator oscillator (DRO) that locks to a 10 MHz stable local oscillator (STALO). The output of the up-converter mixer is routed to a solid-state high power amplifier with 40dB gain. The amplified signal is then radiated through the antenna via a circulator. The transmitted waveform is centered at 5.3GHz with 20MHz bandwidth. A prototype RF transceiver has been developed, where both range detection and radar cross section (RCS) measurement capabilities are verified in the field experiments [5].

3. Calibration

The transmitter and the receiver of the MASAR system have been tested in laboratory and outdoor environment. Subsystem performance test, RF feedback calibration, and internal calibration are done in the laboratory to verify the performance of transmitter and receiver. Outdoor experiments are conducted to demonstrate the capability of the system in range detection and radar cross section (RCS) measurement.

In subsystem performance test, both transmitter and receiver are tested. Transmitted power is monitored and signal waveform is verified. For the receiver chain, the noise floor is measured and the receiver gain is
determined. For receiver testing [5], a chirp signal with center frequency 5.3GHz and 20MHz bandwidth is injected into the front end of the receiver. The down-converted signal will range from 5 to 25 MHz. The digitized down-converted signal is shown in Figure 2. The noise floor of the receiver system is approximately -70 dB and the system gain is around 35 dB.

4. Field Measurement Setup and Discussion

Several field experiments for two-dimensional SAR imaging will be carried out to verify functionality of the subsystems of airborne SAR. The proposed field site is the Malacca campus football field of Multimedia University, which is a low reflection outdoor environment. The block diagram of the field measurement system is shown in the Figure 3.

A probe fed rectangular patch antenna will be used to transmit and receive the electromagnetic wave. The minimum distance between the antenna and measured target is 50.88m for far field requirement and the patch antenna diameter is 1.2m. Point target calibration technique is utilised for external calibration. One known artificial point targets, 12” conducting sphere is used in the field measurement. A styrofoam column with dielectric constant (close to the air) is used as the supporting structure of the conducting sphere. The styrofoam column is positioned in such a way that the surfaces are always seen at angles well away from the direction of the surface normal to minimise scattering from the column surface. All the system components and equipment of MASAR transmitter and receiver will be placed on a trolley. Besides, a track for the trolley to move will be fabricated. The proposed length of the track is 20m.

The chirp waveform is transmitted by the antenna and the return echo is recorded and analysed. The SAR signal processing is based on Range-Doppler processing algorithm for this field measurement. The range reconstruction ($x_n$) processing is realised by combining the I and Q signals and converting the time-domain
data to frequency-domain using Fast Fourier Transform. For the cross range reconstruction \((y_n)\) from this field measurement, consider the geometry of Figure 4, the distance from the radar to the 12” conducting sphere is:

\[
R = \sqrt{(X_c + x_n)^2 + (y_n - u)^2}
\]

Figure 4: 2D image reconstruction Geometry.

The received signal can be written [6] in the form of

\[
s(t, u) = \sum_n \sigma_n \exp[j\omega(t - \frac{2\sqrt{(X_c + x_n)^2 + (y_n - u)^2}}{c})]
\]

(1)

\[
s(t, u) = \exp(j\omega t) \sum_n \sigma_n \exp[-j2k\sqrt{(X_c + x_n)^2 + (y_n - u)^2}]
\]

(2)

where \(k = \omega/c\), \(\sigma_n\) is reflectivity of \(n_{th}\) target, \(X_c\) is center point of target area, \(u\) is synthetic aperture and \(c\) is speed of light.

After range reconstruction process, the received echoed signal is given by:

\[
s(\omega, u) = \sum_n \sigma_n \exp[-j2k\sqrt{(X_c + x_n)^2 + (y_n - u)^2}]
\]

(3)

The distance expression can be approximated using binomial series expansion:

\[
\sqrt{(X_c + x_n)^2 + (y_n - u)^2} = X_c + x_n + \frac{(y_n - u)^2}{X_c} + ....
\]

(4)

Thus received and reference signals can be approximated as Eq. (5) and (6):
\[ s(\omega, u) = \sum_n \sigma_n \exp[-j2k(X_c + x_n + \frac{(y_n - u)^2}{2X_c})] \] (5)

\[ s_0(\omega, u) = \sum_n \exp[-j2k(X_c + \frac{u^2}{2X_c})] \] (6)

where the reference signal is assumed from a unit reflector at broadside of the target.

The instantaneous frequency of received signal is:

\[ ku(u) = \frac{d\theta}{du} = \frac{-2ky_n}{X_c} - \frac{-2ku}{X_c} \] (7)

Since \((y_n - u)^2 \ll X_c^2\), the instantaneous frequency of reference signal is:

\[ ku_o(u) = \frac{d\theta_o}{du} = \frac{-2ku}{\sqrt{X_c^2 + (y_n - u)^2}} \approx \frac{-2ku}{X_c} \] (8)

The difference between IF of reference with IF of target would be:

\[ \Delta ku = ku(u) - ku_o(u) = \frac{2ky_n}{X_c} \] (9)

Thus cross-range can be determined by

\[ y_n = \frac{\Delta ku X_c}{2k} \] (10)

From the range and cross range reconstructions processing, a 2-D image will be formed from this field experiment.

### 5. Conclusion

Preliminary testing and calibration were carried out to verify the capability of the MASAR transmitter and receiver subsystems. Radar hardware system design of the MASAR is presented. The field experiment setup is outlined which provides two-dimensional image resulting from range and cross range detection.

### REFERENCES