Algorithms and Mechanics Employed For Successful Portable Imaging via the SCI-Xe Microwave Imaging System

John Ashton
Sensor Concepts, Inc.
2405 Research Drive
Livermore, California 94550

Scott Gordon
Sensor Concepts, Inc.
350 East Ridgecrest Boulevard, Suite 106
Ridgecrest, California 93555

ABSTRACT

Sensor Concepts, Inc. has developed the SCI-Xe Portable Microwave Imaging System prototype for use in the assessment of the low observable (LO) characteristics of fielded military platforms in their native environments. The SCI-Xe is a single man deployable suitcase-size system that employs a small linear rail in order to acquire linear synthetic aperture radar (LSAR) data in the 8-18 GHz frequency range. Data collections are performed via a single button push and the data is stored on a removable harddrive for comparison to an existing database for analysis.

Recent deployment of the SCI-Xe prototype has provided excellent feedback on the viability of performing repeatable field measurements using alignment techniques that do not significantly affect the overall system size and weight. The SCI-Xe employs a video camera and uses video image algorithms such as edge detection, thresholding, and overlay masks to provide a simplistic coarse alignment to a stored baseline position. Once positioned, a single LSAR collection is performed to provide the radar data necessary for analysis, which includes a robust image registration algorithm to first, perform a quantitative assessment of the positioning accuracy and second, align the data for further image filtering and statistical processing.

Keywords: RCS Measurements, Radar, Radar Cross Section, Imaging

1.0 Introduction

The original concept of the SCI-Xe was to develop a man-portable diagnostic microwave imaging tool in order to provide field maintainers a defect analysis capability. The radar, computer, and user display are all contained within a suitcase-sized enclosure for portability. A single interface cable attaches the radar to a pair of antennas. The software is designed to provide measurement feedback immediately via data comparisons to an on-board database. The system collects coherent LSAR data which be processed to provide diagnostics images or further analyzed with more advanced algorithms.

For the system's first deployment, it was configured so that the user held the antenna head and performed LSAR data collections by physically sweeping the antennas in a linear path. Motion errors due to sweep inconsistencies were compensated for using a sophisticated motion compensation algorithm.

Actual field use indicated that the handheld concept, although possible, was not optimal. Positioning errors due to human inconsistencies could degrade the data collections to the point were the mocomp was not able to provide valid corrections, thus making the system less robust. To provide high quality data collections, a small motor driven rail was added to perform the LSAR scans. In addition, a tripod mounted jib was added for greater elevation coverage (Figure 1).

Figure 1 – SCI-Xe system

A combination of a coarse video alignment system and image registration processing are used to provide repeatable positioning and data products.

2.0 SCI-Xe Imaging System

The SCI-Xe radar is based on the SCI-1000 imaging system and utilizes a Linear FM Homodyne receiver. The system is run in a transmit while receive (ungated) mode and therefore uses separate transmit and receive antennas. This mode of operation allows the unit to use very low transmit power, yet still provide excellent sensitivity. Any appreciable range aliasing is also eliminated with the use of this mode. The SCI-Xe uses 4 GHz of bandwidth centered within the 8-18 GHz spectrum and is capable of collecting both vertical and horizontal polarizations. The nominal measurement range is 10 feet to the center of the measurement zone with a ± 4 foot range window. Although the system is capable of longer range measurements, the 10 foot range center was chosen in order to minimize contamination from clutter in the vertical dimension (i.e. ceiling, floor) as it cannot be spatially separated via an LSAR image processing. Additional clutter suppression is provided via a small shroud that surrounds the antennas. Crossrange motion is provided by a small motor driven linear rail (currently 36 inches in length) with sampling set sufficiently fine to provide an alias-free crossrange of more than twice that of the downrange dimension. Typical collections are performed in roughly 2-3 seconds.

The SCI-Xe utilizes a COTS Windows®-based computer and is easily upgraded to faster processor speeds if necessary. Current technology harddrives contain enough storage capacity to handle tens of thousands of datasets.

3. Alignment Technique

Alignment of the SCI-Xe system relative to the target is a crucial step to the overall robustness of the system, yet it must be relatively quick in order to be viable for repeated field use. The alignment of the SCI-Xe is a simple two step process and is based around the use of a video camera mounted between the antennas in the antenna head. First, a tri-view like that shown in Figure 2 is displayed to the user based on the selection of pre-defined target zones. This tri-view contains views designed to orient the user to the region of the platform that is to be measured. Included are a topdown view of the measurement orientation via a wireframe overlay of both target and measurement location, a video snapshot of the target zone as viewed from the antennas, and an option target RCS image. The user positions the SCI-Xe to the approximate location shown in the images.

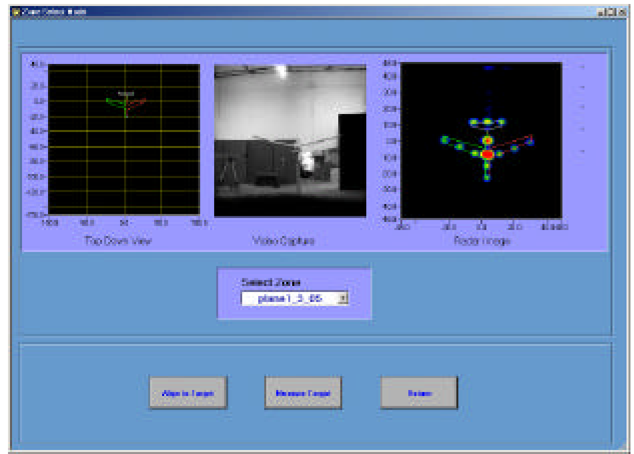

Figure 2 –SCI-Xe Tri-view

The second step is a coarse video alignment. To aid this process, a dual view is displayed as shown in Figure 3 which features a comparison of a stored baseline view (right) and a "live" image (left).

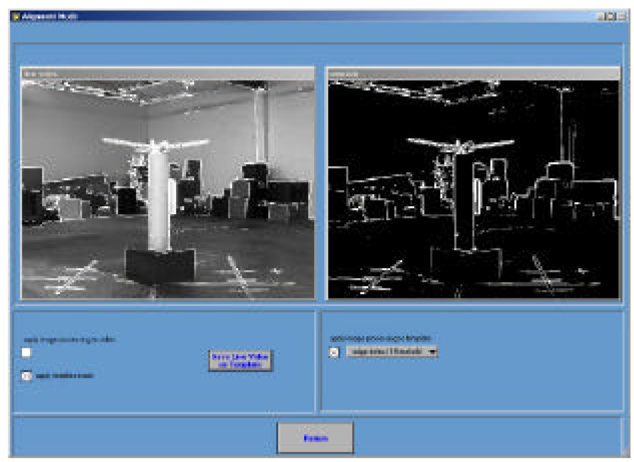

Figure 3-Video alignment

A wireframe overlay is created from the baseline video image via an edge detection algorithm and is applied over top of the current live video image. The SCI-Xe is then positioned, with the live video and overlayed wireframe serving as immediate feedback to the user.

4. Data Collection

Once positioned, the user needs only to press a collect button. The antenna head is scanned along the linear rail while the data is collected and stored to a removable harddrive. After the scan is completed, the data is processed into a 2-D image and then registered to the selected zone's baseline image from the database. The amount of miss-registration in the current image is compared to user-defined translation thresholds in downrange, crossrange and aspect angle to determine if the data collection is valid. If a threshold is exceeded, the user is prompted with the amount of miss-registration and instructed to move the SCI-Xe and re-collect the data.

5. Data Processing

After a data collection has successfully passed the registration process, it is then prepared for final processing and analysis. Image processing is crucial in providing the spatial separation necessary for the data registration and filtering steps utilized in the SCI-Xe. Without these steps, corruption from unintended scattering would bias the dataset and make analysis difficult.

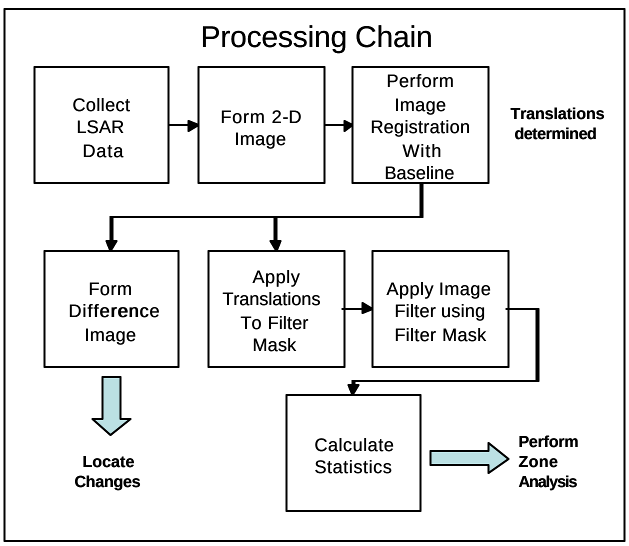

Figure 4 – SCI-Xe Processing Chain

Image Formation, Image Registration

These two processes are actually performed immediately after the data collection is finished and are used to determine the validity of the dataset (as noted in the Data Collection process). The image registration is performed by pixel aligning the current image with the stored baseline image, and translations determined from the image miss-registration (downrange, crossrange, and aspect angle) are saved for the filter re-alignment process.

Difference Image

After registering the current image, a difference image is formed to provide visual change detection. To eliminate false alarms in the difference image due to slight registration errors, an algorithm is used which differences neighborhoods of pixels rather than individual pixels. Noise floor thresholding and visible dynamic range are user selectable parameters.

Image Filtering

The next step is to remove unwanted scattering from the image scene which may include background or unintended target features. Stored with the baseline dataset is an image mask that is applied to the image in order to filter around a particular region of the baseline target zone. Based on the translations determined in the previous step, the baseline image mask is adjusted to fit the current dataset. The images in Figure 5 are from a simulated dataset and depict the adjustment of the image mask.

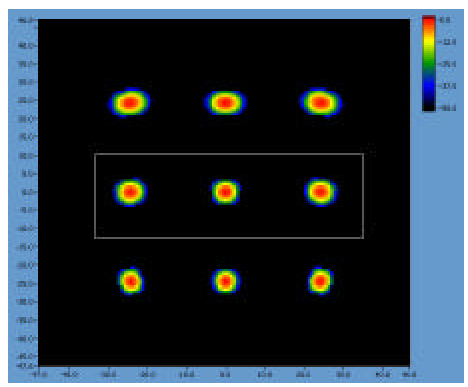

Figure 5a – Baseline Image and Mask

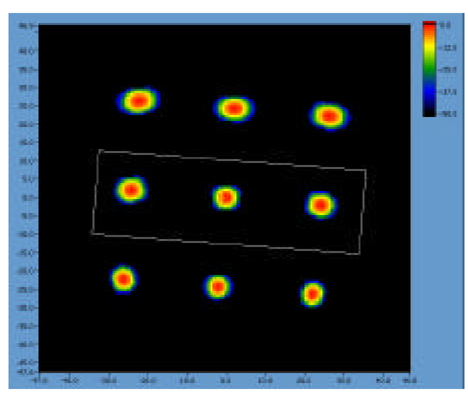

Figure 5b – Miss-registered Image and Rotated Mask

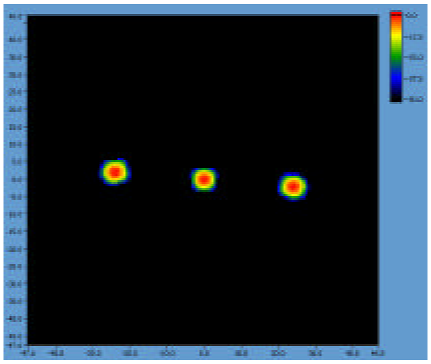

Figure 5c – Filtered Image

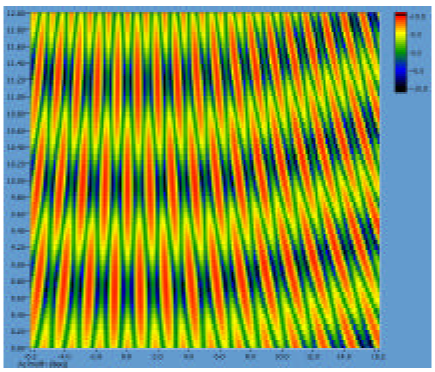

Figure 5d – Global RCS Plot of Filtered Data

Image-based filtering is a process that allows a user to define a region in an image and to extract the I/Q data associated with the scattering in that region. It can be thought of as multiplying a 2-D mask to the image (1 for pixels in the region of interest and 0 elsewhere) and applying an inverse 2-D fft to generate filtered I/Q data. The actual code is more involved to allow for the possibility of different window functions, polar reformatting, zero padding, and near field keystone distortion correction.

Edge effects in the filtered data can be greatly reduced by applying data extrapolation, using a Burg autoregressive model for stability. When this option is chosen, data is extrapolated prior to imaging and the mask is applied to the extrapolated data image. The image data is transformed back to I/Q and only non-extrapolated data is retained.

Statistics

Once image filtered and transferred back to the I/Q domain, statistics can be applied to both baseline and current datasets in order to help assess the overall health of the target zone. The goal of the SCI-Xe system is to maintain flexibility in this area of processing in order to provide the best quantitative analysis for each platform. On a given platform, different zones may have drastically different scattering mechanisms and angle/frequency dependencies and, therefore, will need different statistical analysis. The SCI-Xe is designed to incorporate these processing requirements into the database for use with each individual zone. Figure 6 shows an example of using Wideband RCS (average amplitude over frequency) for comparing the current dataset to a baseline.

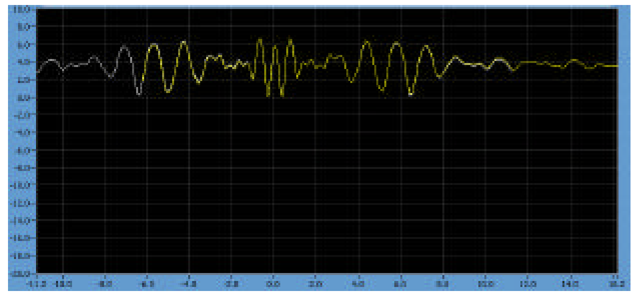

Figure 6 – Wideband RCS Plot Comparison (WBRCS vs. Aspect)

7. Summary

A method for providing repeatable diagnostic data to help assess the health of fielded LO systems has been shown. The SCI-Xe system is easy to use and its small footprint allows for quick deployment which is crucial for field usability.

8. REFERENCES

[1] John Ashton and Scott Gordon, “Compact RCS Imaging System”, Proceeding of the 23rd Annual Meeting of the Antenna Measurements and Techniques Association (AMTA ‘2001), p. 112, October 2001.