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Automatic Identification of Satellite Features from Inverse Synthetic Aperture Radar (ISAR) Images

Andrew Begg, Eric Rogers, Bing Chu and Xiaohao Cai

***Abstract*— Inverse Synthetic Aperture Radar (ISAR) images are a popular and effective tool used in the modern age to identify moving targets, particularly in the airborne and space arenas. Much research has been undertaken on the automatic recognition of targets in this area, applying computer vision algorithms to the two dimensional image maps produced when measuring targets via this method. In this document we discuss an on-going programme of work to fully automate space target recognition, and specifically here outline a methodology proposed for automating the identification of specific features of space targets, in order to aid the confidence of an operator making the final decisions. Large scale results are still currently being collected for the project.**

I. Introduction

The theme of surveillance has significantly benefited from more recent developments in computer vision and machine learning algorithms, with many systems now able to fully automate the classification process of an unknown target entirely from the digital signals collected by the sensors of the system. Examples of this have been used in both military and commercial applications [1], in the maritime and airspace domains. These often take advantage of radar sensors because of the large region they can survey continuously. This principle of automated target classification can be applied to space targets, where again, targets are measured via a radar and the output can be processed by machine learning algorithms.

This piece of research uses simulated Inverse Synthetic Aperture Radar (ISAR) output, which produces a two dimensional image of reflected points on the target as down and cross-range plots. The area has attracted novel exciting research in the past few years [2], here we detail some of the on-going work to use computer vision techniques to classify space targets by identifying structures on the satellites that can be used for identification. The research discussed here fits into a larger programme of work that aims to fully automate the processing, discrimination and classification of space targets, using data fusion of multiple independent models and automated assessments. ISAR outputs are able to show good information of the physical shape and features of a target, it is hoped to be used in conjunction with other measurements that provide different information about the system being assessed. By using multiple data sources, the confidence in the classification can be increased as well as some explanation as to why an overall conclusion has been reached by the model, this is essential for systems that have operators in overall control.

Andrew Begg, Eric Rogers, Bing Chu and Xiaohao Cai are with the Department of Electronics and Computer Science, University of Southampton, Southampton, SO17 1BJ, United Kingdom. Email: asmb1v21@soton.ac.uk; etar@ecs.soton.ac.uk; b.chu@soton.ac.uk; x.cai@soton.ac.uk

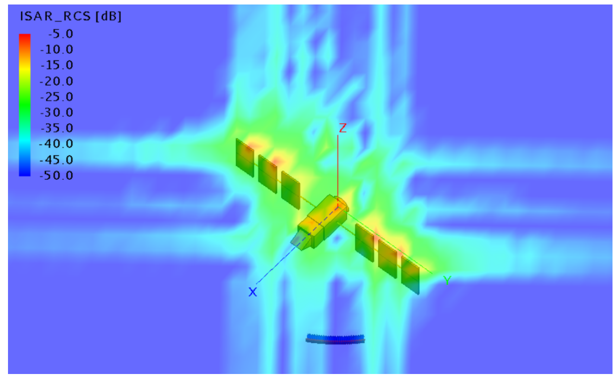

Fig. 1. ISAR image of an ocean monitoring satellite produced by Altair's FEKO.

II. Methodology

Four models have been produced, three satellites and one representing a final stage rocket capsule. All four models are based upon simplified versions of real world systems. Two commercially available software packages have been identified as suitable for producing the ISAR images, the Ansys Electronics Suite 2023 [3] and Altair's FEKO 2022 [4] however, both programs are first principle level solvers and require significant compute time to produce each image.

For an initial platform to study the concept, a basic ISAR emulator was constructed in Python. The tool takes a CAD model as an input and allows for scaling and full rotational operations on the mesh. An image of each requested permutation of the model is returned in a format similar to an ISAR image that would be produced by the aforementioned first principle suites. This is done by calculating the incident rays on the target from a source, and determining which rays would typically return a suitable reflection from the target. A simple edge detection function is then applied to the resultant image, so that features can be more easily identified. Images were compared with the FEKO tool and suitable agreement for the initial study has been achieved, examples of an image from each source are shown in Figures 1 and 2 respectively.

A dataset consisting of 100 images of each target was generated, in each image the target in question was rotated to a random pose. Additionally, through a combination or

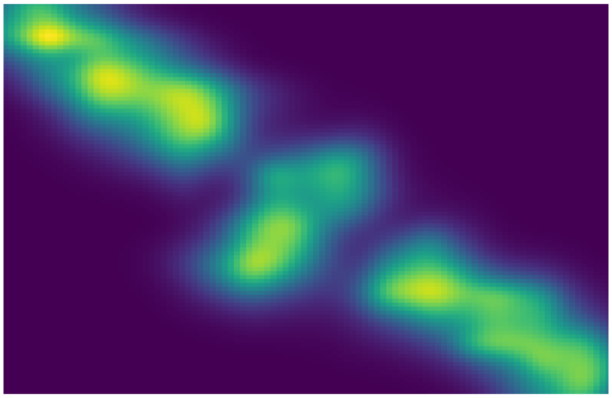

Fig. 2. Simulated ISAR image of the same ocean monitoring satellite CAD model shown in Figure 1 generated by the bespoke Python tool.

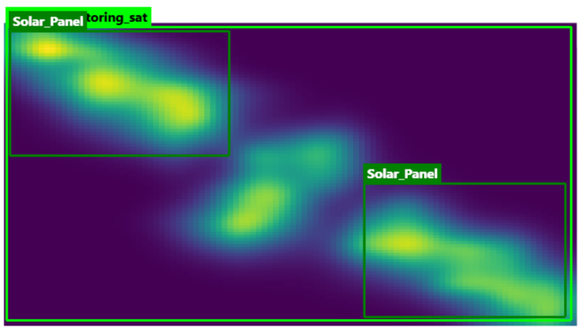

Fig. 3. Simulated ISAR from Figure 2, with additional labeled features for model training.

scaling and modifying the number of rays emitted from the pseudo-radar, the equivalent image resolution was varied for each produced image. The constructed data-set was split into the traditional train, test and validation.

Many different classes of satellite have unique structures protruding from their central body in order to carry out specific functions. These often are similar across families of satellite and could be used as a discriminator. Therefore, user created labels were overlaid around certain components of the models in the images, an example of this is shown in Figure 3. The purpose of labelling components is to explore the possibility of visually identifying parts of the measured target that an operator may be able to use to verify and increase their confidence in the predictions of the model. In the example shown in Figure 3, only the large solar panels are labelled however, the study uses a range of ISAR resolutions and on those with higher detail, features such as the lens can be identified and have been labelled accordingly. The YOLO (You Only Look Once) [5] model architecture was used as an initial platform for the research as the model has the component (object) identification functionality out of the box.

III. Results

At this stage of the research, the result are only preliminary and being iterated upon as greater understanding of the problem is being developed however, some initial results are discussed here. The first iteration looked at just two models, a satellite and a rocket body. ISAR images were generated of each from random orientations but fixed distances. The trained model was able to correctly identify the two models in 100 percent of the un-seen 15 test images. Knowledge learnt from this phase has been used to design the second iteration and results are currently being processed and analysed for presenting to the community shortly.

IV. Discussion

The preliminary results collected so far show significant promise for the future work, as the complexities are increased and understood better, the capabilities of the model are also expected to increase. As mentioned, the first iteration achieved a 100 percent accuracy on the small sample of test data used, this has been assessed as attributable to the significant differences in the features of the models used and thus creating distinct patterns in the ISAR images. For the next iteration, sub-classes of satellite with similar features have been used, as well as varying distances (resulting in reduced image resolution in many cases). A key area being explored currently in the second phase are the limitations of the model with the random pose and range to target, this problem has been identified by [2] and the authors propose an angle-agnostic feature extraction method to mitigate it with significant success, a similar approach may be required for this problem.

V. Future Work

The work showcased here represents a smaller and idealised version of the real world problem. As the project has yielded promising results, future workstreams to better emulate the scenario are already being considered. The areas thought to be most beneficial to understand subsequently are: using noisy images with erroneous returns and blurred data points; progressively diminishing the image resolution to better represent the long range measurements that may be required in the space domain; and increasing the number of categories of target and types of each respectively.

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