Department of Electronic & Electrical Engineering

BEng/MEng in EEE/EDS/EES/EME: 19.496/EM401 Individual Project

INTERIM REPORT

- A draft e-copy of the report (as pdf file and entitled "name_interim-report") must be submitted online via MyPlace by 12h00 on Friday 01 December 2023.
- The final e-copy must be submitted (and confirmed) by Friday 08 December at 12h00. (The draft submission from 01 December will be considered as the final submission after the deadline.) No submission will be permitted after 08 December.
- Formal written feedback will be provided after the project oral in January.

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Project Title: Investigation into Information Extraction from Raw SAR Data using AI Approaches		

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Declaration

By submitting the work, I am confirming that that I have read and accepted the University policy and hereby declare that this work has not been submitted for any other degree/course at this University or any other institution and that, except where reference is made to the work of other authors, the material presented is original.

A key part of project conduct and reporting is the requirement to compare current progress to that anticipated in any previous reporting stage and then highlight where changes have occurred, the reasons for the changes and the actions taken in response to such changes. As part of the interim report, students are required to reflect upon the progress of the project to date, reflect upon on the degree to which this progress has met expectations and intimate the impact that such changes have had on the planned project objectives and deliverables. Limited to this current page. Comments should be simple and clear. Not duplicate content from main body of interim report.

A. Project Objectives

There has been no change to the project objectives at this point in the project. It is still believed that the key objectives laid out in the Statement of Intent remain relevant and achievable to the overarching goal of the project. At this point, the key objective remains to deliver a solution that can improve the current processing of SAR data using deep learning methods. Ideally, this will be achieved by using a neural network to analyse only the raw data to extract valuable information, for example to find a ship in a large volume of data mainly made up of blank ocean.

B. Project Progress:

So far, the project has progressed as according to plan. The main task currently being undertaken is the design of the processing framework as planned. While I am pleased that the project has remained on track I think more could have been achieved during this phase of the project. This is due to the significant research that has been required during this phase which I recognise as being extremely valuable however I think I could have taken a more parallel approach in research and processing framework design to allow the start of implementation sooner. The use of more parallel task working has been considered and taken into consideration when adjusting the project plan for the remainder of the project.

C. Project Deliverables:

The project deliverables have remained unchanged up to this point of the project. This is largely due to the intensive research nature of this phase of the project and the concentration on design as opposed to implementation. From the research and processing framework design work it seems that the projects deliverables are feasible so I am confident the project can proceed as planned. However, I recognise in the next steps I may come across challenges that impact major decisions in the project which is why I have scheduled dates for major decisions to be made. This should reduce the impact of any challenge as if it is too significant to overcome if I make my major decision on time the project delivery deadline will not be impacted.

Project Context & Background

1. **Synthetic Aperture Radar**
From research [1], Synthetic Aperture Radar (SAR) can be described as a form of radar data collection used in a variety of tasks both civilian and military such as monitoring flooding, volcanoes, and deforestation. It collects data from an active sensor, active sensor since receiving energy emitted by itself, by emitting bursts of electromagnetic energy (typically microwaves) from a moving emitter (chirps) and receives the energy returned after being reflected (echoes). The SAR system can measure the amplitude and phase of the portion of the echo received in the sensor(backscatter). The strength of this signal received is referred to as the backscattering coefficient (dB). Using this data typically SAR systems then go on to perform processes to produce grayscale images of the scene they are surveying. The information these images contain is vital to the tasks described beforehand however the computational costs of producing these images are high and processes are inefficient. A proposed method of reducing costs is to analyse the raw SAR data and perform target recognition using deep learning methods which is the area this project concentrates on.

As described above SAR data is generated by processing the echoes of pulses it has emitted that have reflected off a target area. When dealing with this raw data acquisition method two directions are referenced, range and azimuth. Range is the distance from the radar to the target along the line of sight (line pulse travels along from radar to target) and the azimuth is the angle between the platform track and the target (along-track dimension) [2]. These as well as other key variables in SAR such as swath and incidence angle are demonstrated below in Figure 1 [3].

The raw data acquisition model can now be summarised [4]. The pulse used in the range direction can be defined by a real-valued linear frequency modulated (LFM) characteristic as seen below in Equation 1.

$$spul(\tau) = \omega r(\tau) \cos\left(2\pi f0\tau + \pi Kr\tau^2\right) \quad (1)$$

In Equation 1, w_r represents the range envelope which is the region in which the radar operates effectively in range direction, f_o is the radars centre frequency which is the frequency separating the upper and lower sidebands of a modulated signal (carrier frequency) [5], Kr is the LFM rate (rate of pulses) and τ is the fast time which is the duration of each pulse [6]. The echoes returned to the radar of each pulse are stored in a single-dimension matrix for a given azimuth.

The radar continues on its track and as it does so it continues to transmit and receive pulses at a known time interval which is known as the pulse repetition interval (PRI). Each subsequent echo for a new azimuth is stored in a new row of the matrix which generates a two-dimensional matrix of the data as the azimuth is changing as SAR is a moving platform. Figure 2 below demonstrates the acquisition process of the raw SAR data described above.

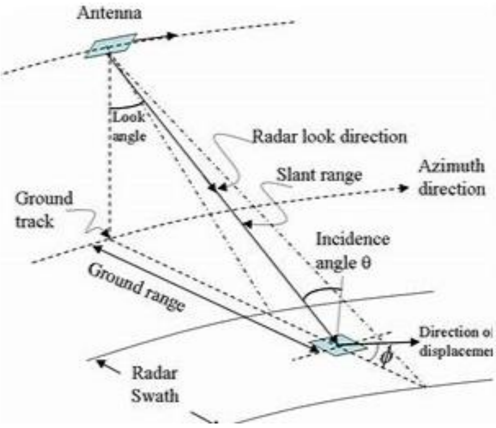

Figure 1- Diagram of basic SAR variables

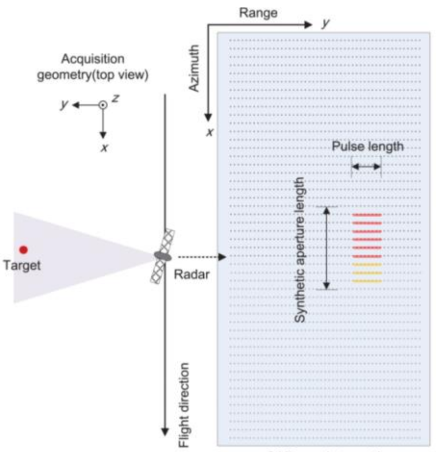

Figure 2- Diagram of raw SAR data extraction

Next, the radar carrier is removed from the signal typically through quadrature demodulation. Quadrature demodulation results in a complex number [7] which is then stored in a two-dimensional matrix that makes up the raw SAR data. The raw SAR data can be derived as shown in Equation 2:

$$sbb(\tau, \eta) = g\ (\tau, \eta) \otimes h(\tau, \eta) + n(\tau, \eta) \quad (2)$$

In this modelling of raw SAR data g is the reflectivity of the ground and h is the impulse response of a single point target which is found from Equation 3:

$$h(\tau, \eta) \approx \omega r\left[\tau - \frac{2R(\eta)}{c}\right] \omega a(\eta - \eta c) \exp\left\{-\frac{j4\pi R0}{\lambda b}\right\} \times \exp\{-j4\pi Ka\eta^2\} \times \exp\left\{j\pi Kr\left(\tau - \frac{2R(\eta)}{c^2}\right)\right\} \quad (3)$$

Where w_a is the azimuth envelope, R is the instant range and R_0 represents the shortest range. Finally in Equation 2 n represents the noise present. This demonstrates the complexity associated with the processing to achieve SAR imagery as each cell of data represents a complex value, which across a frame can be thousands of complex numbers. Since many frames make up a scene the computational costs rapidly increase as complex operations are required for each cell to process the data into a SAR image. These findings demonstrate the motivation to achieve information extraction from the raw SAR data without first processing it into an image.

To summarise, the raw SAR data acquisition outputs a two-dimensional matrix made up of complex numbers. Figure 3 below shows the image generated as an example from the real parts of some SAR raw data. These results were obtained in MATLAB using a script to generate synthetic raw SAR data. This script allows the user to produce a database of images containing a selected shape (dot, plane, etc) where each frame could contain a given number or a random number of each shape. The script can then take this database of images and convert each frame to complex raw SAR data. The work on this script has been crucial to the project as it provides an unlimited amount of variable raw SAR data containing ground truths for use during the project. Normally to make this data readable to the human eye significant offboard processing must take place using methods such as the Range-Doppler method [8] which are computationally expensive and are not information-enriching. Therefore, the process isn't increasing the information in the image but is instead transforming it into a viewable format which means in theory that all information contained in the image seen below in Figure 4 [9] which is an example image of a ship at sea taken using SAR is equivalent to that of the raw data. This means that if a ship is contained in the raw data it should be possible to extract that information. To do this a deep learning method which specialises in pattern recognition will be used which would be impossible for a human to achieve by viewing the raw data by eye alone.

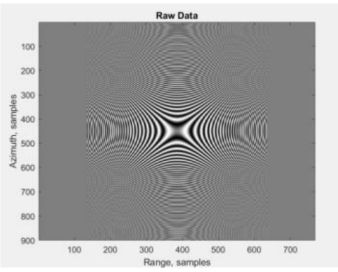

Figure 3 - Plot of real raw data from synthetic data of an image containing a dot

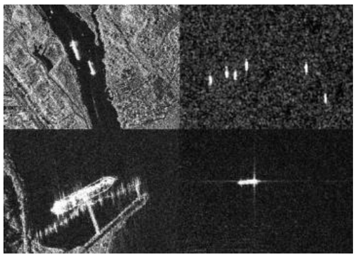

Figure 4 - Example SAR imagery of ships at sea with raw data to be potentially analysed with deep learning

2. Deep Learning

As discussed earlier, this project's AI approach to analyse raw SAR data is a deep learning network. To summarise [10], deep learning is a subset of machine learning which is in turn a subset of Artificial Intelligence and refers to the use of artificial neural networks made up of multiple layers inspired by similar structures present in the human brain. These types of networks can learn complex patterns and relationships from large volumes of data and therefore are suited to the task of analysing large amounts of data from SAR.

This project has focused on Convolutional Neural Networks (CNNs) as it has been found from the following research [11] that they have a high performance working with matrix datasets like that of raw SAR data. The architecture this project has concentrated on is Resnet18 due to its particularly high performance with images, which raw SAR data resembles, as found in project research [12]. A CNN architecture is made up of several layers. The main layers are the Input layer which passes data into the network, Convolutional layer, in Resnet18 17 convolutional layers of 3x3 kernels are used, which using filters extracts information from data, the Pooling layer which lowers the computational costs by downsampling the data input and the Fully Connected layers produce the results for the data passed into the network, which could be the probability of a defined class being present in the data. An example structure of a basic CNN can be seen below in Figure 5 [13]. The network can use various methods to optimise the processing of the data such as backpropagation. This project will utilise the CNN and its properties of complex pattern recognition and aim to use the raw SAR data as an input from which the CNN can learn to recognise patterns. Then when given further data it can determine if targets are present in the raw data. For example, we could feed the network with raw data we know to contain ships (ground truths) to train the network. We could then feed raw data containing blank sea as well as ships and if successful the network will be able to pick out when the data contains ships. This would meet the project objectives since it would lower the computational costs as we would be able to extract information from raw SAR data without the costly process of producing images first.

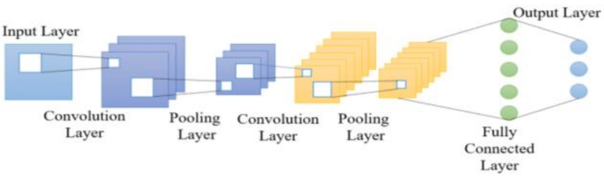

Figure 5 - Architecture of simple CNN

Project Plan – Gantt Chart - Landscape

Figure 6 - Gaant Chart displaying Project Plan

Discussion of Project Plan, Technical Risks, Ethics, Sustainability & EDI

1. Project Plan Overview

While formulating the project plan the main prioritisation has been to assign tasks to be completed in the most efficient order. This includes where possible aligning tasks that are related to one another as well as working on tasks where possible in parallel instead of running the project in an entirely linear manner.

As can be seen from the project plan several major decision points are approaching for the project. The first of these decisions is the final programming language implementation. This will be a decision between using either MATLAB or Python for the final implementation of the CNN. This decision will be made around week 26. This decision will be aided by the work implementing the processing framework with synthetic data.

Another key decision to be made is the final performance assessment criteria. This represents what is used to assess results and draw conclusions for this project so will be crucial to assessing the project's performance. This decision will be made around week 29 as by this point the model should be nearly completed. It should be noted however that by this point the metrics will already have been considered and this is merely a final selection of those most relevant and best at effectively assessing the success of the project as these metrics were researched as part of the processing framework design stage.

Another key aspect of the project plan is identifying ahead of time busy periods of work where work objectives overlap. The most significant of these periods has been identified between weeks 25 and 27 of the project work plan. It will be crucial during this time to be successful to operate on these tasks in parallel as the neglect of any of these tasks could have serious impacts on the overall project plan as one of these tasks includes a major project decision. Any delays here could have a domino effect on later scheduled tasks so a key focus will be delivering these objectives on time.

Finally in the project plan slip weeks have been included. This is to reflect that in the final weeks the only planned work is report writing which has been purposefully spaced out as tasks will be able to be worked on in parallel with this. These slip weeks are added to show that the final few weeks have been underloaded in terms of work so should any potential delays in work take place there is time allotted at the end of the project to catch up. However, if no catch-up is required this time could be used to alternatively work on any outstanding stretch objectives.

2. Technical Risk Assessment

For the project to be successful it is crucial to demonstrate that risks to the project's deliverables have been identified and any possible mitigations have been carried out. Project risks are rated from 1-4 based on both their severity and their likelihood and a risk factor is taken by the product of these ratings. A score of less than or equal to 2 represents low risk, between 2 and 5 is a moderate risk, between 5 and 9 is rated a high risk and anything greater than 9 is rated a critical risk. Table 1 below displays the technical risks to be considered with the project, the mitigating actions that have been taken and their associated risk factor.

Table 1 - Table displaying project risks and their associated risk factors

Risk (N)	Mitigating Action	Risk Factor
Insufficient Data to Train AI Model (1)	Synthetic SAR Raw Data generation script created providing unlimited raw data to train network	MODERATE
Loss/Corruption of Files (2)	Backup copies of project files maintained on University C drive as well as on personal laptop	LOW
Insufficient Available Time in Lab (3)	Have checked remote access is available on lab computer to allow out of hours working in lab	LOW
Absence due to Illness/Unforeseen Circumstances (4)	Slip time incorporated into project plan to account for any absence/delays to project	MODERATE
Unsuccessful Delivery Using only Raw Data (5)	Project goals emphasise improving efficiency of SAR data processing, ideally using only raw data however any improvement to the process can be seen as successful.	HIGH

3. Sustainability & Ethics

Throughout the project, best effort has been made to align with the sustainability and ethics outlined in the Statement of Intent. The project remains aligned with the United Nations Sustainable Development Goal (UNSDG) number 9 "Industry Innovation and Infrastructure" [14]. This project aspires to innovate the processing of raw SAR data by significantly reducing the offboard processing costs. This will allow more efficient and sustainable on-board processing of the data which will lead to improvements in the industry. These improvements can lead to significant positive impacts on both societal and environmental issues. For example, some of the environmental uses of SAR include oil spill detection[15], wildfires, flooding [16], deforestation, volcano and earthquake monitoring [17]. It is clear then to see if successful the impact the work in this project can have and demonstrates the great value the work being produced can have to benefit humanity as laid out in the UNSDGs by driving the innovation of technology used widespread such as SAR.

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