Glasgow College, UESTC

Project Specifications and Preliminary Report on UESTC4006P(BEng) Final Year Project

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Project tittle	**Synthetic Aperture Radar (SAR) Image Generation based on Generative Adversarial Network and Target Characteristics**
Source of project: Scientific Research	
Expected Outcomes: Software	
Research content of the project	**1. Research status and development trend** With the dramatic increase in computer computing power, Machine Learning (ML) and Artificial Intelligence (AI) has become one of the most widely applied technologies today, with tremendous number of research conducted in related area. Deep Learning (DL) is part of a broader family of machine learning methods based on artificial neural networks (ANNs) with representation learning, which is by far the most popular type of method among the machine learning techniques. Generative Deep Learning, also known as Deep Generative Models, is an increasing popular class of deep learning models that generates deep-fake data based on real data. Generative deep learning has applications in various fields, such as text generation, image generation, audio generation and even video generation. Classic deep generative models include *Restricted Boltzmann Machines (RBM)*, *Variational Autoencoders (VAE), Flow-based Models, Generative Adversarial Networks (GAN)* and currently the state-of-the-art *Diffusion Models.* What involves in this project is mainly GANs, which is the most well-known method in generative deep learning. Since introduced by Ian Goodfellow and his colleagues in 2014, GANs are regarded as “the most interesting idea in the last 10 years in Machine Learning” by the top researcher in this area and have been fully developed through these years. Extensive research leads to a number of variants, including but not limited to DCGAN, CGAN, WGAN-GP, SNGAN, CycleGAN, InfoGAN and StackGAN. Currently, leading research combines GANs with Transformers. This means that GANs can be used in multimodal tasks. With the help of self-attention and multi-head-attention mechanism, a stronger GAN can be created than those mentioned above. Generative Adversarial Networks has always been the best choice when it comes to building a generative model after it is introduced. However, recently GANs’ priority seems to be taken by Diffusion Models. Diffusion models consumes much

more computational resources than GANs and as a result, the level of realism of generated data is higher than GANs. It is believed by researchers that diffusion models have overcome some of the drawbacks of generative adversarial networks, for example, mode collapse and gradient vanishing.

However, even generative adversarial network is not the most advanced solution in generative models currently, it is still of high research value. Because GANs achieves data generation in an innovative idea, behind which the theory can be easily understood by even the beginners in machine learning.

2. Topic selection basis and significance

The title of this project is *Synthetic Aperture Radar (SAR) Image Generation based on Generative Adversarial Network and Target Characteristics*, which aims to generate deep-fake SAR images using Generative Adversarial Networks.

SAR (Synthetic Aperture Radar) is an active earth observation system that can be installed on aircraft, satellites, spacecraft, and other flight platforms to observe the earth around the clock and all-weather and has certain surface penetration capability. Therefore, SAR system has unique advantages in disaster monitoring, environmental monitoring, marine monitoring, resource survey, crop estimation, mapping, and military applications, and can play a role that is difficult to play by other remote sensing means. The distance the SAR device travels over a target during the period when the target scene is illuminated creates the large synthetic antenna aperture. In general, the greater the aperture, the higher the image resolution, regardless of whether the aperture is physical (a huge antenna) or synthetic (a moving antenna) – this enables SAR to produce high-resolution images with relatively small physical antennas. Hence, SAR systems are increasingly valued by countries around the world.

Since SAR is a type of remote sensing technique, the images are typically in large scale. Therefore, multiple types of objects may be contained in one SAR image. Based on this fact, it is possible to combine SAR images with machine learning techniques to achieve something marvelous. For example, object detection (*YOLO*, *Mask R-CNN,* etc.) can be applied to find certain object in SAR images. This may help to locate enemy targets in military operations. Another example is that modern neural network can construct 3D scenes based on 2D images. 2D SAR images can be used to simulating the real 3D environment in certain locations.

However, machine learning and deep learning are big-data-based techniques. Without adequate number of data, without sufficiently large data set, even the state-of-the-art algorithm cannot achieve the assigned tasks. This fact indicates that if we need to design a machine learning model that is expected to have satisfactory performance on SAR images, we should firstly have enough number of SAR images that feed the model. Meanwhile, the cost of taking SAR images is relatively high. The price for building a big database that only consists of real SAR images is great.

Thus, it is of great significance to find methods that can generate deep-fake SAR images that are enough to pass off as genuine, which is the reason for having this project.

3. Project Research Content

This **research content** in this project is to implement different types of GANs that can generate SAR images by using a widely popular deep learning framework, ***PyTorch***. Comparisons between different types of GANs will be made to find the most optimal one among them. Initially, the author plans to implement these types of GANs:

1) GAN

   The original type of generative adversarial network based on dense-connected neural networks, the multilayer perceptron.

2) Deep Convolutional Generative Adversarial Network (DCGAN)

   Add convolution layers to GAN to have better performance.

3) Wasserstein GAN (WGAN) or Wasserstein GAN Gradient Penalty (WGAN-GP)

   A type of generative adversarial network that minimizes an approximation of the Earth-Mover's distance (EM) rather than the Jensen-Shannon divergence as in the original GAN formulation.

The type of GANs above may be changed in the author's research process. If time permits, the author will try other methods apart from those mentioned above.

The images in the database which the author applies to train those GANs are real and small-scale SAR images of seven different types of military vehicles, totally over 5000 images.

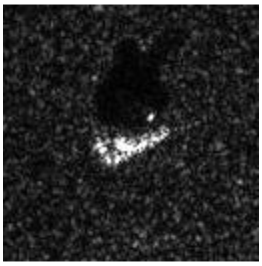

Figure 1. One of the SAR images in database

4. Key problems and final goals to be solved, as well as the main theories,

technical routes and implementation plans to be adopted

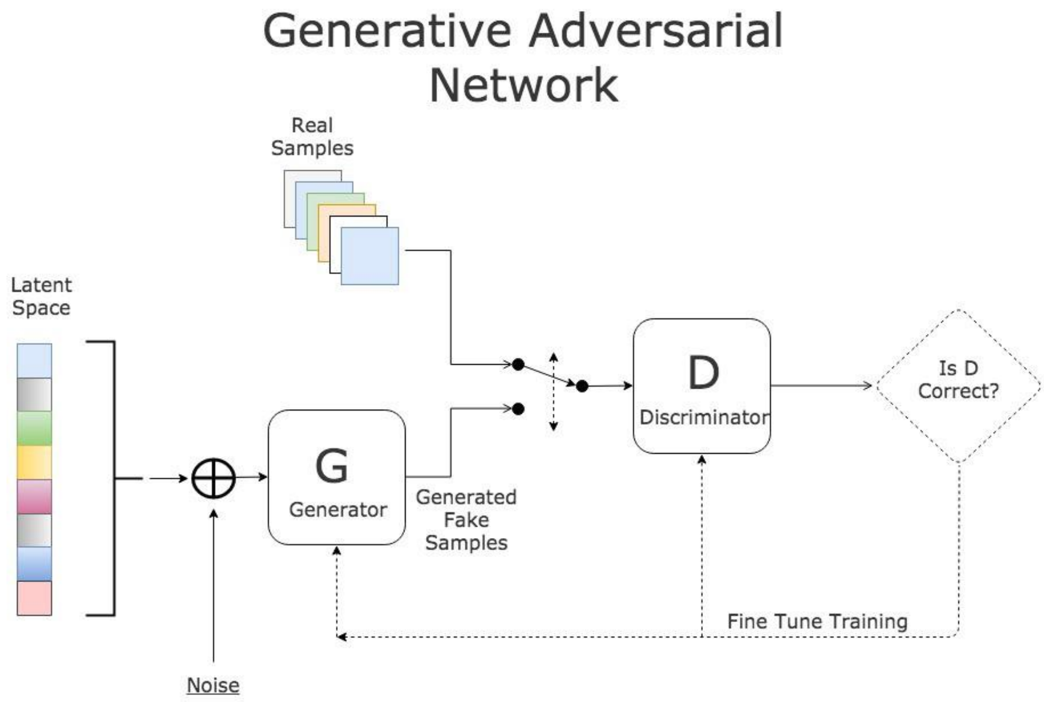

Figure 2. The structure of GAN

The **main theory** behind generative adversarial networks is adversarial learning. GAN simultaneously trains two neural network model: a generator G and a discriminator D. G captures the distribution of real data and imitate them to generate fake data. D estimates the probability that a given input data came from real ones rather than G. Two neural networks contest with each other in the form of a zero-sum game, where one agent's gain is another agent's loss. The loss function for G (Loss G) describes the "distance" between generated fake image to the real image. The smaller Loss G is, the more realistic the image generated by G. The loss function for D (Loss D) measures D's ability to distinguish between real and fake data. The smaller Loss D is, the better D's distinguish ability will be. In the training of GAN, with the help of back-propagation algorithm and optimization function, we aim to reduce Loss G and Loss D by fine tune the parameters in the two neural networks. As a result, a powerful generator that can generate photorealistic data as well as a powerful discriminator that is able to classify images into the right category (real or fake) with high accuracy. In this project, "data" above refers to SAR images.

The author believes that the **key problems** in this project are the following:

1) Preprocessing of SAR images
   Usually, proper preprocessing leads to faster convergence speed and higher performance in neural network models. But sometimes, they work better if the data remains raw and unchanged.
2) Determining the hyperparameters
   A hyperparameter is a parameter in machine learning whose value is used to

influence the learning process. In general, they are important factors that has impact on model performance.

3) Avoid common problems that exists in GANs
   a) Vanishing Gradients
      A situation that would occur if discriminator were much more powerful than generator. In this scenario, the loss function of D will suddenly go down to 0, making generator untrainable.
   b) Mode Collapse
      A very common problem in GAN's training where discriminator gets stuck to a local minimum in loss function and generator can "cheat" discriminator by generating repeated data. As a result, the trained generator only generates a set of similar data even if the training data is various.
   c) Failure to Converge
      Frequently met in the training of GAN. The causes are various.

The **final goal** of this project is implementing different GANs to generate SAR images and find the best model among them.

Technical routes and **implementation plans:**

	Expected Start Date	Expected Deadline
Contact Supervisor	2022.04	2022.04
Acquire basic knowledge of Machine Learning and Deep Learning	2022.04	2022.07
Learn operations in PyTorch	2022.07.01	2022.07.31
Learn basic theories behind Generative Adversarial Networks	2022.08.16	2022.09.15
(Planned) Read papers about GANs and usage of GANs in image generation	2022.10.07	2022.12.01
Write Project Specifications and Preliminary Report	2022.10.20	2022.10.31
(Planned) Implement model using original GAN	2022.12.01	2022.12.15
(Planned) Implement model using DCGAN	2023.01.05	2023.01.20
(Planned) Implement model using WGAN/WGAN-GP	2023.01.30	2023.02.15

(Planned) Try alternative generative deep learning methods	2023.02.20	2023.03.05	
(Planned) Comparison between models	2023.03.10	2023.03.15	
(Planned) Writing final report	2023.03.20	2023.04.20	

5. Project characteristic or innovation points

As machine learning, especially deep learning, is becoming increasing popular in research and in industry, the lack of training data seems to be a barrier for transferring neural network model to specific areas. Combining SAR remote sensing imaging with deep learning faces the same problem since the cost of acquiring SAR images is high. This project aims to apply generative deep learning technique: Generative Adversarial Networks to resolve this problem. With GANs, the database of SAR images can be extended with neglectable cost compared to taking real SAR images. In short, using deep learning to overcome obstacles in deep learning.

6. References

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Supervisor Review and Approval	The student has a good understanding of this project. The research programme is reasonable, and the relevant research plan is detailed, which shows that the student is well-prepared. Signature: Zongyong Cui Date: 2022.10.26