Towards an accelerated frequency estimation of sparse signals using deep learning

A digital radar generates huge amount of data every second. The data contains information about electromagnetic reflections from a varying number of targets that could correspond to aircrafts or boats, but could also correspond to reflections from ground, sea and rain. It is a challenging problem to process all the data in real time, to transform terabytes of raw data to high quality tracks indicating how the targets move. In a broad sense, this thesis examines the problem of how the process of signal data analysis can be accelerated. In practice, this would enable radars to faster detect, localise and keep track of fast moving threats in the form of hostile fighter jets or missiles, which is crucial for taking defensive actions. More generally, the methods examined in this thesis do not necessarily solely apply to radar applications, but also to sonar and other applications concerning sensing of electromagnetic signals.

Anything that can be measured over space and time can be seen as a signal. Some of the most common examples of signals are in the form of audio, image, or radar signals. In radar applications, the radar sends out a beam of light, although of a wavelength not directly visible by humans, and receives its echoes from the environment. This is analogous to how the human eye perceives photons reflected off objects. Stronger echoes are received from targets such as aircraft or rain clouds. The composition of all these echoes which the radar receives make up the so-called target scene.

Using signal processing, information that is not directly observable from a signal can be extracted and analysed. One form of such processing is through the computation of a signal's spectrum, namely the frequencies that constitute the signal. This is analogous to how visible white light is composed out of all the colours of the rainbow, which can be experimentally shown by the famous prism-experiment where a beam of white light passes through one side of a prism and exists as a rainbow (its spectrum, where one colour corresponds to one frequency). Using frequency estimation of a radar signal, the estimated frequency components can then be used to determine where targets are located.

The problem at hand is the following: given an observed signal, the target scene is to be obtained. In other words, given a signal, the number of targets and their locations are to be determined. As mentioned, this can be done by first extracting the frequency components of a signal. In this thesis, an observed signal is assumed to consist of a small number of frequencies that take values among a so-called frequency grid. The frequency grid is simply a set of frequencies from which a signal's frequency components can take their values. More specifically, the number of targets in the target scene is assumed to be small, where each target gives rise to one frequency component, making the signal so-called sparse. Each frequency gives information about the location of a target in the target scene. A probabilistic model that assigns how probable each of the frequencies on the frequency grid are is used. Frequencies with high probabilities can then be said to be frequency components of the observed signal. However, what if the true frequency components of the signal do not align exactly with the assumed frequency grid? This problem is alleviated by adjusting the signal model in such a way that the estimated frequencies are allowed to lie between and outside the frequencies of the frequency grid.

The algorithm for computing what frequencies a signal consist of is computationally heavy. The core of this thesis lies in the investigation of how this algorithm can be accelerated using novel deep learning methods. To become acquainted with the deep learning model used for this task, more specifically a continuous conditional generative adversarial network (CCGAN), a number of subproblems were more or less solved before attacking the main problem at hand, which was that of computing what frequencies a signal consists of. Even though the resulting CCGAN model showed poor results, knowledge in the area of CCGANs has been gained. Moreover, interesting problems to be further dealt with have been illuminated and suggestions for future work have been made. Further results of this thesis are more theoretical, consisting of mathematical derivations concerning the methods used in the thesis, essentially complementing the literature on the subject.