Permanent National Test Bed for Passive Radar Testing and Qualification

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***Abstract*— This paper overviews the current development state of a permanent test bed for passive radar. The computational challenges of developing a permanent multistatic passive radar test bed are discussed, and the effects of implementing sparse signal reconstruction on a graphics processing unit (GPU) is discussed.**

I. INTRODUCTION

A traditional radar requires a dedicated transmitter, making them expensive, power hungry, needing a spectrum license, and easy to locate [1]. The Council for Scientific and Industrial Research (CSIR) has been involved in the development of passive radar systems (frequently referred to as a passive coherent location (PCL)) to explore the advantages and challenges carried by the negation of a dedicated transmitter, in favor of exploiting a third-party illuminator [2]. The lower costs of a passive radar can allow for much wider deployments, gap-filling and improved flight safety.

In collaboration with the University of Cape Town and local company Peralex, the CSIR demonstrated operational nodes able to detect aircrafts from around 2012. Now the CSIR expands the work on passive radar, with a goal of supporting the local passive radar industry and enabling new applications in air traffic monitoring and air traffic control (ATC). The technology required for real-time PCL, such as fast digital signal processors, computers and graphics processing units (GPUs) became cost efficient only recently, and so the PCL is yet to be accepted for use in commercial ATC applications. It is assumed that the main barrier to this acceptance is the lack of an established track record of performance under varying environmental and flight conditions. The CSIR is establishing a national PCL test bed to obtain such data collected over an extended period of time and under such various environmental and flight conditions.

II. SYSTEM DESCRIPTION

The test bed currently consists of a central node and 6 radar nodes positioned around O. R. Tambo airport. Each node in the network operates as an independent passive radar. These nodes receive commercial frequency-modulated (FM) transmissions reflected by an aircraft (or aircrafts) to perform detection. The the results are then passed through a standard internet protocol (IP) network to be fused and converted into tracks.

Fig. 1. Surveillance phased array.

Each node consists of three antennas, an RF-frontend, a digitizing receiver, and a mid-spec PC. One antenna is used to receive a reference of the FM broadcast, while the other two (shown in Fig. 1) receive the reflections from the aircraft. Once digitized, the reflections are around 90–140 dB lower than the reference signal and are therefore masked by sidelobes [1]. In order to recover the reflections, sparse reconstruction is performed [3] using an orthogonal matching pursuit (OMP) [4] algorithm.

The detections are then stored and combined to form tracks at the central node. They are combined using a Bayesian filter implementation. Currently the system has been able to detect commercial aircraft at bistatic ranges of over $600\,\mathrm{km}$, while costing a fraction of a commercial active radar.

The system currently has six operational bistatic pairs, with 1 more still to be commissioned. The current configuration is shown in Fig. 2. The black circle in Fig. 2 represents the $100\,\mathrm{km}$ range from O. R. Tambo International Airport.

The system is currently gathering data, which will be used to study the coverage and detection probabilities, etc., against commercial ATC data. The probability of detection, tracking ability and limitations of the system will be investigated.

III. COMPUTATIONAL CHALLENGES

The computational challenges in the system arrive mainly for the real-time processing requirement of the system, combined with the need for adaptive filters and sparse reconstruction to effectively detect targets [5]. In order to be competitive with traditional search radars, this processing and update periods

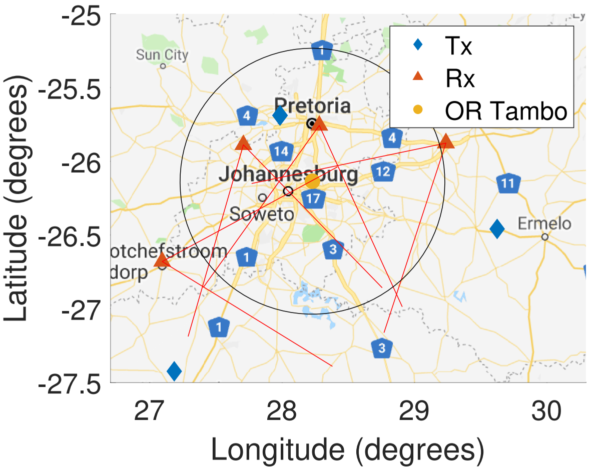

Fig. 2. Current system configuration.

are required to be comparable to the traditional radar's scan period, which is typically between 1–4 seconds.

A. Sparse Signal Reconstruction

The sparse solution attempts to express $\mathbf{y}$ as

$$\mathbf{y} = \mathbf{\Psi}\mathbf{x}, \tag{1}$$

where $\mathbf{\Psi}$ is a sparse matrix consisting of the direct-path, clutter and target returns form aircraft, and $\mathbf{x}$ is the weighting associated with the signal components in $\mathbf{\Psi}$.

In the case of this system, a 4-second block of data is passed through the compressed sensing reconstruction algorithms, such that $\mathbf{\Psi}$ is a $260{,}000 \times 800{,}000$ matrix. Typically, $\mathbf{\Psi}$ comprises of less than 1000 significant components. For this problem size, OMP was used to reconstruct the signal as it can exploit the low density of $\mathbf{\Psi}$ to accelerate the computation.

B. Implementation

In order for the reconstruction to occur in real time, the parallel nature of the algorithm is exploited, and the processing is employed on a GPU. In this case specifically on a NVIDIA GPU GTX 1060. It was however, discovered that the optimisations presented in literature [4], [6] were not optimal for implementation on GPUs. This is because the majority of computation is performed by fast Fourier transforms, matrix-vector operations, and dot products. While these operations are parallelisable, they have a low arithmetic intensity, which stifles the effective throughput of GPUs.

The ratio between floating point operation rate, and memory load rate for the current offering of NVIDIA GPUs is shown in Fig. 3. Here it can be seen that the range of GPUs can perform between 60 and 127 operations for each value that can be loaded from memory. This demonstrates the value of using operations that increase the arithmetic intensity of the algorithms implemented. On-chip caching is able to reduce the required memory throughput, but due to the large problem size, the benefit is limited.

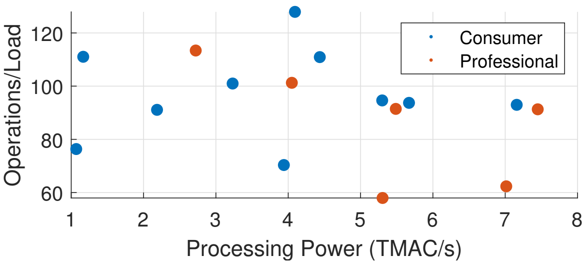

Fig. 3. Memory to computation ratio of current NVIDIA graphics cards.

In order to fully utilize the GPUs' resources, the iterative loop in the OMP algorithm was batched. This allowed the most processing intensive operations [3] to be changed from a matrix-vector multiplication to a matrix-matrix multiplication. In this system the alteration from using a set of matrix-vector multiplications to a single matrix-matrix multiplication reduced the reconstruction's mean processing period from 12.34 s to 2.93 s.

IV. CONCLUSION

A permanent test bed for long term passive radar testing and qualification was showcased. The key computational challenge was highlighted. It was shown that the real-time algorithm needs to not only be computationally efficient, but the algorithm selection and design must also be aware of the limitations and characteristics of the processor on which it is to be implemented. The limitation of arithmetic intensity on GPUs was highlighted, and the requirement to adapt the algorithms employed is the system was shown.

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