HIGH PERFORMANCE COMPUTING FOR HYPERSPECTRAL IMAGE ANALYSIS: PERSPECTIVE AND STATE-OF-THE-ART

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1. ABSTRACT

Hyperspectral imaging is concerned with the measurement, analysis, and interpretation of spectra acquired from a given scene (or specific object) at a short, medium or long distance by an airborne or satellite sensor [1]. The wealth of spectral information available from latest-generation remotely sensed hyperspectral instruments [2] (hundreds of spectral bands in nearly-continual wavelength channels) has quickly introduced new challenges in the analysis and interpretation of hyperspectral data sets. It is expected that, in future years, hyperspectral sensors will substantially increase their spatial and spectral resolution (imagers with thousands of spectral bands are currently under development). Such wealth of spectral information has opened groundbreaking perspectives in many applications, including environmental modeling and assessment for Earth-based and atmospheric studies, risk/hazard prevention and response including wild land fire tracking, biological threat detection, monitoring of oil spills and other types of chemical contamination, target detection for military and defense/security purposes, urban planning and management studies, etc. The incorporation of hyperspectral imaging instruments on airborne and satellite platforms is currently producing a nearly continual stream of high-dimensional data, and this explosion in the amount of collected information has created new processing challenges in several remote sensing problems [3].

In this paper, intended to serve as an introduction to a special session focused on high performance computing for hyperspectral image analysis, we describe the state-of-the-art and future perspectives in the area of high performance computing (HPC) applied to hyperspectral imaging studies. The utilization of HPC systems in hyperspectral imaging applications has become more and more widespread in recent years. It should be noted that HPC implementations do not exclusively rely on computer architecture-based advances. Quite opposite, important developments in algorithm optimization for low-complexity implementations have been successfully developed in order to complement hardware-based improvements when designing computationally effective hyperspectral imaging techniques, including data compression approaches [4].

Focusing on hardware-based improvements, one of the most widely used approaches is based on using COTS (commercial off-the-shelf) computer equipment, clustered together to work as a computational “team.” This strategy, often referred to as Beowulf-class cluster computing, has already offered accesses to greatly increased computational power, but at a low cost (commensurate with falling commercial PC costs) in several hyperspectral imaging problems [5, 6]. In theory, the combination of commercial forces driving down cost and positive hardware trends (e.g., CPU peak power doubling every 18–24 months, storage capacity doubling every 12–18 months, and networking bandwidth doubling every 9–12 months) offers supercomputing performance that can now be applied a much wider range of remote sensing problems [3].

Although most parallel techniques and systems for image information processing employed by NASA and other institutions during the last decade have chiefly been homogeneous in nature (i.e., they are made up of identical processing units, thus simplifying the design of parallel solutions adapted to those systems), a recent trend in the design of HPC systems for data-intensive problems is to utilize highly heterogeneous computing resources [7]. This heterogeneity is seldom planned, arising mainly as a result of technology evolution over time and computer market sales and trends. In this regard, networks of heterogeneous COTS resources can realize a very high level of aggregate performance in hyperspectral imaging applications.

Despite hypespectral imaging algorithms generally map quite nicely to parallel systems made up of commodity CPUs, these systems are generally expensive and difficult to adapt to onboard remote sensing data processing scenarios, in which low-weight and low-power integrated components are essential to reduce mission payload and obtain analysis results in real time, i.e., at the same time as the data are collected by the sensor. In this regard, an exciting new development in the field of commodity computing is the emergence of programmable hardware devices such as field programmable gate arrays (FPGAs) [8], which can bridge the gap towards onboard and real-time analysis of remote sensing data. FPGAs are now fully reconfigurable, which allows one to adaptively select a data processing algorithm (out of a pool of available ones) to be applied onboard the sensor from a control station on Earth. On the other hand, the emergence of commodity graphics processing units GPUs [9] (driven by the ever-growing demands of the video-game industry) has allowed these systems to evolve from expensive application-specific units into highly parallel and programmable commodity components. Current GPUs can deliver a peak performance of 1 Teraflop (e.g., the NVidia Tesla C1060[1] GPU) and up to 4 Teraflops (e.g., the NVidia Tesla S1070[2] GPU) which is several times the performance of the fastest dual-core processor available. The ever-growing computational demands of hyperspectral imaging applications can fully benefit from compact hardware components and take advantage of the small size and relatively low cost of these units as compared to clusters or networks of computers.

The main purpose of this paper is to provide a taxonomy of available HPC-based implementations of hyperspectral imaging algorithms on multi-core (CMP, chip multi-processor) and multi-processor (SMP, symmetric multi-processor) systems, multi-computer clusters, large-scale and heterogeneous networks of computers, grid computing environments, and specialized hardware architectures such as FPGAs and GPUs. Combined, the revision of existing techniques conducted in this review paper, along with their detailed presentation in the form of algorithm taxonomies delivers an excellent snapshot of the state-of-the-art in the area of HPC-based processing of hyperspectral imagery. The paper also offers a thoughtful perspective of the potential and emerging challenges of applying HPC paradigms to hyperspectral imaging problems in different application domains.

2. REFERENCES

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