IMPROVING THE SCALABILITY OF PARALLEL ALGORITHMS FOR HYPERSPECTRAL IMAGE ANALYSIS USING ADAPTIVE MESSAGE COMPRESSION

Antonio Plaza, Javier Plaza, and Abel Paz

Department of Technology of Computers and Communications
University of Extremadura, Avda. de la Universidad s/n, E-10071 Caceres, Spain
Phone: +34 927 257195 – Fax: +34 927 257203
Contact e-mail: aplaza@unex.es

1. INTRODUCTION

High performance computing has become a standard solution in order to deal with high response times in large-scale remote sensing applications [1]. For instance, a trend in geocomputation is to utilize highly heterogeneous and distributed parallel platforms which can benefit from local (user) computing resources in order to efficiently store and handle high-dimensional data archives resulting from latest-generation imaging instruments such as NASA Jet Propulsion Laboratory's Airborne Visible Infra-Red Imaging Spectrometer (AVIRIS) [2], which can record the visible and near-infrared spectrum (wavelength region from 0.4 to 2.5 micrometers) of the reflected light of an area 2 to 12 kilometers wide and several kilometers long using 224 narrow spectral bands. Such heterogeneous networks of computers (HNOCs) enable the use of existing computing resources and provide incremental scalability of hardware components. As a result, well-tuned parallel programs can be easily scaled to large configurations because additional workstations can always be added to the HNOC [3]. In the context of hyperspectral imaging applications, it has been demonstrated that the scalability of parallel algorithms is directly related to the size of the messages to be exchanged through the communication network of the system when the parallel algorithm is run [4], i.e. the latency for large message sizes (typical in hyperspectral imaging applications, since each pixel vector is made up of hundreds of spectral values) is extremely sensitive to the size of the message. Thus, decreasing the size of the messages could significantly reduce the latency and hence improve the scalability or parallel performance. This dependence on the interconnect is even more critical in clusters of computers, where the interconnect is a typically an off-the-shelf hardware such as a Gigabit Ethernet, which suffers from high latency and relatively low-bandwidth. The bottleneck becomes even more severe when the interconnection network is saturated with a large number of processors sending large messages [5].

In this paper, we propose a new framework based on the utilization of message compression techniques for improving the scalability of parallel hyperspectral imaging algorithms on both homogeneous and heterogeneous parallel computers. Specifically, we investigate two techniques of message (pixel) compression: lossless and lossy. Lossless compression involves no loss of information and enables perfect reconstruction of the hyperspectral data after reception. On the other hand, lossy compression involves some *acceptable* loss of information, where the term *acceptable* needs to be substantiated via extensive experiments analyzing the balance between the increase in parallel performance and the potential reduction in algorithm analysis accuracy resulting from the loss of information. Our proposed approach makes use of spectral mixture analysis (SMA) techniques based on endmember extraction and spectral unmixing to achieve lossy compression at different ratios.

2. METHODS

The idea of the proposed SMA-based technique is to represent a hyperspectral pixel vector by a linear combination of a few pure spectral signatures (called *endmembers* in hyperspectral imaging terminology) and their corresponding fractional abundances. SMA assumes that the spectral signature of a pixel (regardless of its spatial resolution and, hence, its pure/mixed nature) can be represented by a linear combination of *endmembers*, weighted by their corresponding fractional abundances. In this work, we use the number of *endmembers* (extracted from the original scene) as a criterion to define the desired compression ratio, where the *endmembers* are automatically found using different algorithms available in the literature [6], such as the pixel purity index (PPI), N-FINDR, iterative error analysis (IEA), and the automatic morphological endmember extraction (AMEE), among others. The fractional abundances are estimated by using a least squares-based fully constrained linear spectral unmixing technique. Lossless predictive coding will also be compared to the lossy framework above, and a new method for adaptive compression based on the spatial homogeneity of spectral signatures across different regions of the hyperspectral scene, able to adaptively select message size for lossy compression, will be described in the final paper.

3. EXPERIMENTAL RESULTS

A preliminary experimental validation has been conducted on two parallel systems: (1) an HNOC with a total of 24 processors distributed among different locations, and (2) a massively parallel NASA cluster, with 256 processors. Two types of applications are explored: (1) unsupervised/supervised classification, and (2) target/anomaly detection. Fig. 1(a) shows the scene used for the first type of application, gathered by AVIRIS and consisting of 1939x677 pixels and 224 spectral bands in the wavelength range 0.4-2.5 mm (574 MB in size). Fig. 1(b) shows the ground-truth map for this scene. Fig. 2(a) shows the scene used for the second type of application, gathered by AVIRIS over the World Trade Center (WTC) area in New York City and comprising 614x512 pixels and 224 spectral bands (140 MB). Fig. 2(b) shows the target locations of the thermal hot spots in this scene. Table 1 shows the classification accuracy (in percentage, measured using a parallel neural network classifier) and the detection accuracy (percentage of area under ROC curve, measured using a parallel RX anomaly detection algorithm) after applying lossy SMA-based compression to reduce message size. Table 1 suggests that lossy compression can lead to improvements in the scalability of parallel algorithms without sacrificing a lot of classification/detection accuracy.

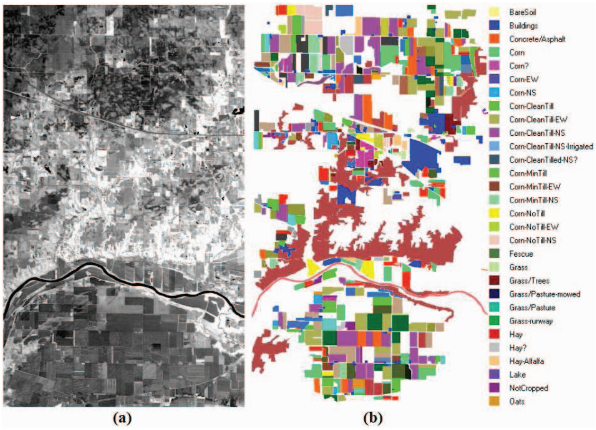

Fig. 1. AVIRIS Indian Pines scene (a) and ground-truth map (b).

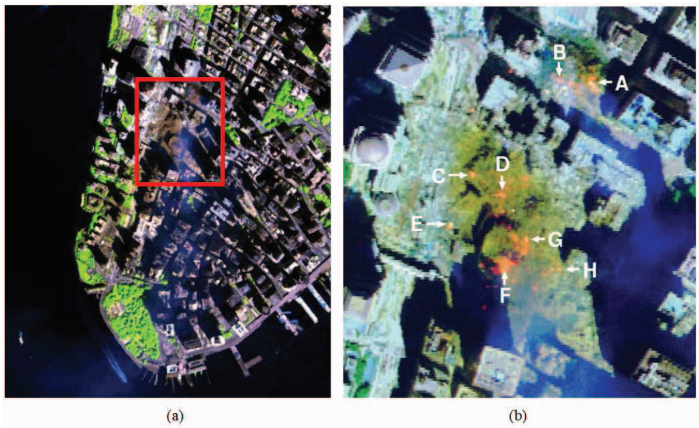

Fig. 2. AVIRIS WTC scene (a) and spatial location of thermal hot spots (b).

	AVIRIS INDIAN PINES SCENE						AVIRIS WORLD TRADE CENTER SCENE					
	HNOC (24 Processors)			CLUSTER (256 Processors)			HNOC (24 Processors)			CLUSTER (256 Processors)		
Method / Ratio	20:1	40:1	80:1	20:1	40:1	80:1	20:1	40:1	80:1	20:1	40:1	80:1
PPI	92.35 (19.45)	90.25 (21.32)	88.91 (22.12)	91.56 (200.4)	90.41 (215.2)	88.99 (226.4)	89.26 (19.13)	88.75 (21.14)	88.03 (22.01)	89.12 (186.8)	88.56 (207.1)	87.91 (216.3)
N-FINDR	92.76 (19.03)	91.06 (20.45)	89.63 (22.44)	93.88 (203.6)	91.12 (219.7)	89.43 (231.0)	89.14 (19.20)	88.50 (21.23)	87.89 (21.95)	89.03 (178.2)	88.33 (203.9)	87.82 (219.2)
IEA	91.89 (19.26)	90.76 (19.96)	88.55 (21.96)	92.46 (199.2)	90.89 (213.7)	89.12 (225.6)	89.19 (18.95)	88.34 (20.44)	88.12 (21.43)	89.33 (173.0)	88.10 (194.1)	87.94 (225.8)
AMEE	92.05 (18.81)	90.85 (20.91)	89.90 (22.55)	92.00 (198.1)	90.92 (218.3)	89.06 (235.5)	88.43 (19.79)	87.98 (20.49)	87.56 (22.12)	88.98 (180.3)	87.65 (200.5)	87.33 (228.7)
Uncompressed	93.31 (18.60)			93.15 (178.46)			90.13 (17.13)			89.93 (154.23)		

Table 1. Classification accuracy (percentage) and target detection accuracy (percentage of area under ROC curve) after applying a parallel neural network classifier and a parallel RX anomaly detection algorithm to the AVIRIS Indian Pines and World Trade Center scenes, uncompressed and compressed with different methods to improve scalability. The speedup (number of times that the parallel version is faster than the serial version) is shown in the parentheses.

4. REFERENCES

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