

USING MULTIPROCESSOR SYSTEMS FOR MULTISPECTRAL DATA PROCESSING

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Procesarea datelor satelitare multispectrale necesită multe resurse și mult timp de calcul. Aceste procesări pot fi accelerate folosind componente hardware capabile de a rula multicore și multithreading. În ultimul timp procesoarele plăcilor video au evoluat și sunt capabile de a executa și operații de uz general. În lucrarea de față se studiază variația timpului de rulare pentru prelucrarea unor imagini satelitare LANDSAT7 din România dintre 1984 și 2000. Studiul s-a făcut pe baza indicilor NDVI și NDWI calculați pe o placă video CUDA și pe procesorul Intel Q6600.

Processing the multispectral data provided by satellites requires numerous resources and computation time. Using multicore hardware and multithreading the computational process can be significantly speeded up. The Graphics has evolved and the GPU can be used for general computations along with graphical specific calculations. In this paper the computation time performance was analyzed while studying a Romanian region using LANDSAT 7 images between 1984 and 2000. The survey was done using the NDVI and NDWI indexes computed on a CUDA-enabled Graphics Card and an Intel Q6600.

Keywords: GPU, CUDA, LANDSAT 7, NDVI, NDWI, multispectral data, Multicore

1. Introduction

Satellite imagery represents the basis for earth science fields (e.g. hydrology, geology, agriculture, vegetation monitoring) and more than 40 biophysical indices (e.g. Normalized Difference Vegetation Index (NDVI) [1], Normalized Difference Water Index (NDWI) [2], leaf area index [3], thermal inertia [4]).

The LANDSAT program is the oldest land surface recording program that includes several Earth observation satellites launched by NASA and U.S. Geological Survey (USGS). The first satellite was launched in 1972 and the latest (LANDSAT 7) was launched in 1999 (technical details in Table 1). [5]

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Table 1

LANDSAT 7 technical details [6]

Swath width	185 kilometers
Repeat coverage interval	16 days (233 orbits)
Altitude	705 kilometers
Quantization	Best 8 of 9 bits
On-board data storage	~375 Gb (solid state)
Inclination	Sun-synchronous, 98.2 degrees
Equatorial crossing	Descending node; 10:00 am +/- 15 min

LANDSAT 7 uses ETM+ (Enhanced Thematic Mapper Plus) which is the extension of the TM (Thematic Mapper) used in LANDSAT 4 and 5. ETM is a multispectral scanning radiometer, that has been operating since July 1999 and saves the images in 8 spectral bands (Table 2). [5]

Table 2

LANDSAT 7 ETM+ spectral bands [6]

Band Number	Spectral Range (microns)	Ground Resolution (m)
1	0.45 – 0.52	30
2	0.52 – 0.60	30
3	0.63 – 0.69	30
4	0.77 – 0.90	30
5	1.55 – 1.75	30
6	10.4 – 12.5	60
7	2.09 – 2.35	30
Pan	0.52 – 0.90	15

The resulting images are stored and processed, being publicly available for various statistics related to land area through USGS EROS Data Center.

Efficient processing of the satellite data is a challenge for both software and hardware. When technological limitations made impossible to increase performance of single core processors, the microprocessor manufacturers switched to parallel architectures, where the CPU (Central Processing Unit) is composed of two or more cores. Each of these cores operates at a lower frequency with lower consumption and improved stability, but the parallel binding of these nuclei results in significant increase over the serial generation of microprocessors, due to the fact that tasks can be performed at the same time.

Hereinafter, using two different parallel architectures, the possible speed up is analyzed for performing a statistic regarding the water, vegetation and buildings using the NDVI and NDWI indexes for the satellite image in Fig. 1, between 1984 and 2000.



Fig. 1. The area analyzed for water, vegetation and buildings

2. Background

A. GeForce GTX 460 versus Intel Q6600

The Compute Unified Device Architecture (CUDA) was released by NVIDIA in 2007 and it allows the Graphics Processing Unit (GPU) to work as a co-processor to the Central Processing Unit (CPU). [7] Being designed for graphical computations, GPU has a highly parallel architecture that focus on data processing rather than data caching and flow control, as can be seen from Fig. 2.

Development of software is easier for GPU, since the CUDA architecture is scalar. The same program will run using a GPU with more or less cores, the difference being the running time (Fig 3). [7]

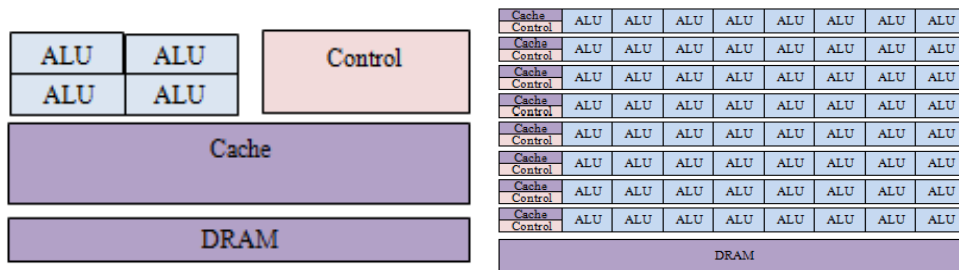


Fig. 2. Schematic architectures of CPU (left) and GPU (right) [7]

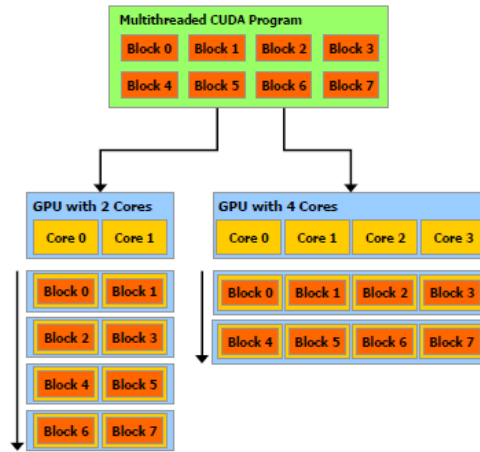


Fig. 3. Automatic scalability for CUDA-enabled processors [7]



Fig. 4. Multithreaded SMs schematic [8]

CUDA Architecture is based on multithreaded Stream Multiprocessors (SMs) (Fig. 4) organized into a scalable array. SMs have a SIMT (Single Instruction Multiple Thread) architecture (one instruction is applied for multiple threads) that enables the multiprocessor to be capable of executing hundreds of threads concurrently. [7]

Each SM contains a Multithreaded Instruction Unit (MT IU) that can schedule and manage up to 1024 concurrent threads, 8 multithreaded SPs (Stream Processors) that support 32-bit and 64-bit integer operations and 32-bit floating point operations, 2 Special Function Units (SFU) that performs interpolations and a Shared Memory. [8]

GeForce GTX 460 SE is a Graphics board compatible with Windows 7 and it supports DirectX 11 with Shader Model 5.0 and OpenGL 4.1. This board is

capable of rendering real 3D scenes (NVIDIA 3D Vision) Additional technical specifications for GeForce GTX 460 SE Graphics Board can be seen in Table 3.

Table 3

Technical specifications for GeForce GTX 460 SE		
GPU Engine	CUDA Cores	288
	Graphics Clock (MHz)	650 MHz
	Processor Clock (MHz)	1300 MHz
	Texture Fill Rate (billion/sec)	31.2
Memory	Memory Clock	1700
	Memory Configuration	1 GB GDDR5
	Memory Interface Width	256-bit
	Memory Bandwidth (GB/sec)	108.8

Q6600 is the first quad-core processor, manufactured by Intel in 2006. In addition to increased number of cores which enables faster execution compared to single core, this processor includes features that enhance performance: Intel® Wide Dynamic Execution enables sending more instructions per clock cycle, Intel® Intelligent Power Capability for better energy consumption, Intel® Smart Memory Access to optimize the use of data bandwidth, Intel® Advances Smart Cache (optimized cache subsystem).

Parallel architecture enables a faster execution for applications that can be at least partially parallelized. Therefore, for certain image indexes (e.g. NDVI, NDWI, etc) and parameters the time needed to extract the information is decreased compared to sequential run.

B. LANDSAT 7

The LANDSAT program contains more Earth-observing satellites all launched by NASA and U.S. Geological Survey. The first satellite was launched in 1972, with the purpose of registering terrestrial images from space. This is the oldest terrestrial surveying program. The last satellite, LANDSAT 7, was launched in 1999. [15]

LANDSAT 7 uses ETM+ (Enhanced Thematic Mapper Plus) which is the extension from TM (Thematic Mapper) which was used by LANDSAT 4 and 5. [15] ETM+ is a multispectral scanning radiometer which has a repetition cycle of 16 days. [16]

At the moment, LANDSAT 7 and 5 are still registering Earth images from space and they perform about 14 full Earth orbits each day, while they can cover the entire surface of our planet in 16 days. [16]

The information acquired is saved and is freely available upon request on USGS Earth Explorer web site [17]. It can be obtained in two formats: JPEG for Natural Color images, Thermal Images and Images with Geographical Reference

or 8 TIF images, one for each band. The TIF images are gray scale, each pixel being stored with 8 bits and having a value ranging from 0 to 255.

C. NDVI, NDWI

In order to perform a survey regarding a region, it is necessarily to use an index. In this paper we will use the NDVI and the NDWI indexes.

NDVI: The NDVI Index, developed by [1], is used to detect the density of vegetation in the area of interest, but it can be used to detect zones with water and bare land. NDVI is computed based on the 3rd and 4th bands from the multispectral images provided by LANDSAT 7:

$$NDVI = \frac{NIR - Red}{NIR + Red}, \quad (1)$$

where NIR is the near infrared band (B4 for LANDSAT 7) and Red is the red band (B3 for LANDSAT 7).

The values obtained lie in the range [-1, 1]. Values lower than -0.4 correspond to water, values above 0.4 correspond to vegetation and the remaining interval represents bare grounds or buildings. The greater the value, the bigger the density of the vegetation for the respective area.

NDWI: The NDWI Index, developed by [2] is used to determine the vegetation water content. It is computed based on 4th and 5th bands from the multispectral LANDSAT 7 images:

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR}, \quad (2)$$

where NIR is the near infrared channel (B4 for LANDSAT 7) and SWIR is the short wave infrared channel (B5 for LANDSAT 7). As the NDVI, the NDWI range from -1 to 1, a greater value means a greater depth of water in vegetation. This index is used for very dense vegetation, for which the NDVI index saturate, therefore it is not possible to make differences in these areas. NDWI values greater than zero correspond to green vegetation, while values lower than zero correspond to dry vegetation. [2]

3. Experiment

A. Software installation

In order to achieve maximum results and performance, the latest drive for the Graphics Board (GeForce GTX 460 SE) [13] and the latest CUDA Toolkit

(CUDA Toolkit 4.0) [14] were used. For seeing more details and being able to make an analysis regarding the cores loading, the number of cores used for processing and for debugging the application, Parallel Nsight 2.0 [18] was utilised.

B. Application description

The input data consists of 8 LANDSAT 7 images taken from the USGS EROS Data Center, Path 183, Row 29. The images are from summertime and were taken from 1984 to 2000. Bands 3, 4 and 5 will be used to compute the NDVI and NDWI indexes for each image.

The images are from the center of Romania have a resolution of 7705x7232 pixels, each pixel having a value ranging from 0 to 255 which is saved on 8 bits.

Reading the input (the images to be processed) is the same for both approaches (computing on the CPU and computing on the GPU), therefore this step is done outside the loop in order to have a more accurate information regarding the run time. Fig. 5 shows the logic diagram in case of GPU processing. The one for the CPU processing is the same, excepting the blocks for data transfer between CPU and GPU which does not exist, the information being directly transferred from memory to processor.

For GPU running, the block grid width chosen is 128 and the block has 256 threads. therefore, the images were 0-padded up to the dimension 8192x8192.

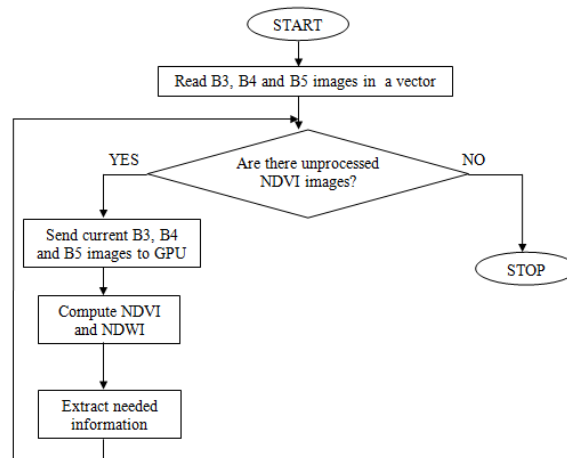


Fig. 5. Logic diagram for computing NDVI and NDWI using GPU

Although there is a big quantity of information that can be extracted using the two indexes, in the present paper the information refers to the amount of water, vegetation and buildings and bare land in the selected area extracted using the NDVI index. Afterwards, using the NDWI index for non-water areas, a

filtering will be performed in the following manner: for NDWI negative values the respective pixel will be considered bare land; otherwise it will be computed as vegetation pixel. The results achieved can be seen in Fig. 6.

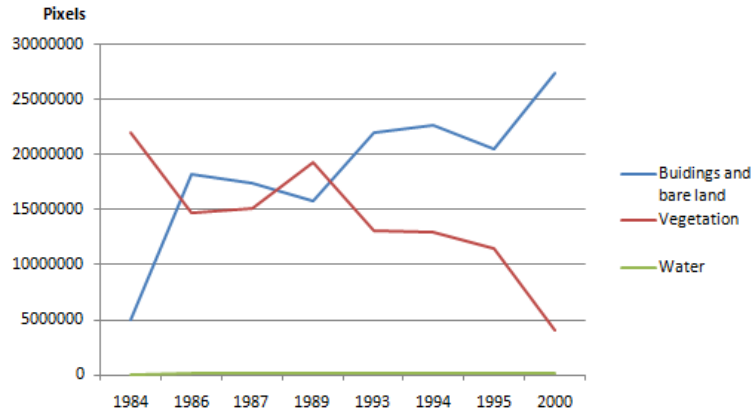


Fig. 6. Statistic of Bucharest neighbourhood between 1984 and 2000 based on LANDSAT 7 images

As expected, the amount of vegetation in the analysed area has dramatically decreased after 1989 due to intensive deforestation and building construction.

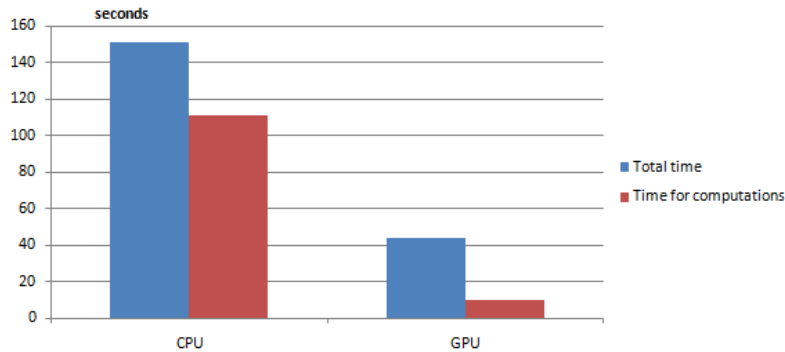


Fig. 7. Time needed to process the NDVI/NDWI on CPU compared to GPU

Using the GPU to perform the computation results in faster processing compared to using the CPU. The time needed only for computations is 111.4 seconds on GPU compared to 10.18 seconds on CPU, resulting a speed up of 10.94 (Fig. 7). The loading of CUDA can be seen below (Fig. 8)



Fig. 8 Loading of CUDA for NDVI and NDWI computation on 8 LANDSAT 7 images

There is no dependency between the processed data, the parallelism being fine-grained. The speed of processing increase with the number of cores and the maximum speed can be achieve for a number of cores at least equal to the number of pixels.

4. Conclusions

This paper presents a possibility to speed up image processing for multispectral data by using highly parallel architecture of a GPU. The speed up is computed using the time needed for computations using an Intel Q6600 CPU and the GPU from GeForce GTX 460 SE.

For the given example, the speed up is not that significant, but facing the situation of needing to process hundreds or even thousands of image, the difference in the amount of time is a notable one.

Using MATLAB, we developed a framework to accelerate the speedup of multispectral data processing. This framework is optimized for multicore processor environments and is a very useful tool for improving the computing time.

We tested and validated our framework on multiple data sets and different processor types. The obtained results are the proof that the correct use of multicore devices can lead to reduced processing time.

We also developed an algorithm for extracting the relevant information from multispectral data obtained from LANDSAT satellite. This algorithm uses parallel processing model to improve the computing time.

In the present paper a speed up of 10.94 was obtained when computing NDVI/NDWI indexes on LANDSAT images between 1984 and 1995, in order to calculate a statistic regarding the amount of water, vegetation and buildings on central Romania and its neighbourhood as well as the medium water index for these areas.

As expected, the amount of vegetation in this area has dramatically decreased. These values can be used to complete surveys regarding the vegetation and building types as well as for the evolution of vegetation over the years.

REFERENCES

- [1] J. W. Rouse, R. H. Haas, J. A. Schell, and D. W. Deering, "Monitoring vegetation systems in the Great Plains with ERTS," in NASA. Goddard Space Flight Center 3d ERTS-1 Symp., vol. 1, pp.309-317, Jan.1974.
- [2] B. Gao, "NDWI – A normalized difference water index for remote sensing of vegetation liquid water from space," Remote Sensing of Environment, vol. 58, pp. 257-266, Dec. 1996.
- [3] S. Garrigues, N. V. Shabanov, K. Swanson, J. T. Morisette, F. Baret, and R. B. Myeni, "Intercomparison and sensitivity analysis of Leaf Area Index retrieval from LAI-2000, AccuPAR, and digital hemispherical photography over croplands," Agricultural and Forest Meteorology, vol. 148, pp. 1193-1209, July 2008.
- [4] A. B. Kahle, J. P. Schioldge, and R. E. Alley, "Sensitivity of thermal inertia calculations to variations in environmental factors," Remote Sensing of Environment, vol. 16, pp. 211-232, Dec. 1984.
- [5] *The Landsat Program*, <http://landsat.gsfc.nasa.gov>, Apr. 2011
- [6] *Landsat 7*, <http://geo.arc.nasa.gov/sge/landsat/17.html>, Apr. 2011
- [7] *NVIDIA CUDA™*, NVIDIA CUDA C Programming Guide Version 4.0, NVIDIA, Mar. 2011
- [8] Ashu Rege, *An Introduction to Modern GPU Architecture*, NVIDIA, 2008
- [9] *GeForce GTX 460*, <http://www.nvidia.com/object/product-geforce-gtx-460-us.html>, NVIDIA, Aug. 2011
- [10] *Intel® Core™2 Quad Processor Q6600*, <http://ark.intel.com/Product.aspx?id=29765>, Intel, Apr. 2011
- [11] E. A. Lee, D. G. Messerschmitt, "Synchronous Dataflow," Proceedings of the IEEE, September 1987.
- [12] G. Kahn, "The semantics of a simple language for parallel programming," in Proc. IFIP Congr., Stockholm, Sweden, Aug. 1974, pp. 471–475.
- [13] *NVIDIA DRIVERS*, <http://www.nvidia.co.uk/object/winxp-280.26-whql-driver-uk.html>, NVIDIA, Aug. 2011
- [14] *CUDA TOOLKIT 4.0*, <http://developer.nvidia.com/cuda-toolkit-40>, NVIDIA, Aug. 2011
- [15] *The Landsat Program*, <http://landsat.gsfc.nasa.gov/>, Aug. 2011
- [16] USGS, "Landsat: A Global Land-Imaging Project", <http://pubs.usgs.gov/fs/2010/3026/pdf/FS2010-3026.pdf>, Aug. 2011
- [17] *USGS Earth Explorer*, <http://edcns17.cr.usgs.gov/NewEarthExplorer/>, Aug. 2011
- [18] *NVIDIA*, "NVIDIA Parallel Nsight" <http://developer.nvidia.com/nvidia-parallel-nsight>, Aug. 2011