DOI 10.18454/PMI.2016.5.706

UDC 681.5

A PARALLEL ANALYSIS OF HYDROLITHOSPHERIC BEDS GEODATA OF NARZAN MINERAL WATER KISLOVODSK DEPOSIT

D.A.PERVUKHIN, Yu.V.ILYUSHIN
Saint-Petersburg Mining University, Russia

The area of the Caucasus Mineral Waters – an environmental spa - occupies a special place among the other spa regions of Russia due to richness, diversity, abundance and value of its mineral waters, landscape and climate conditions, and therapeutic muds. Lately the rate increased of developing its mineral water resources for both the local spa use and bottling for retail consumers.

The growing number of mineral water bottling enterprises and sanatorium organizations affects significantly the amount of mineral water uptake. Irrational water uptake results in deterioration of underground water quality, change of its chemical composition and temperature. Expansion of the depression crater may eventually result in a collapse of seams roofing and vanishing of many water springs. It refers to all the waters underlying the area of Kavkazskie Mineralnye Vody. Due to that situation there is a potential threat of degradation of these deposits of mineral waters.

Therefore, an important task consists in building forecast models of hydro-lithospheric processes in the region while the scope of water uptake changes in various parts of the deposit. it will be based on analyzing aerial photographs taken from board unmanned aerial vehicles. Currently such analysis is conducted using simple linear algorithms.

The paper suggests to use the Nvidia CUDA technology for the purpose, adapting the mathematics used to analyze aerial photographs to that technology. The initial data for processing were obtained by aerial photography in the course of remote sensing of the area by unmanned aerial vehicles belonging to OJSC «Narzan», Kislovodsk, an enterprise for mining mineral water. Presented in this paper have their Author's Certificates issued by the Federal Institute of Industrial Property, the Russian Federation.

***Key words*:** green function, thermal field, discretization step, managed object, analysis, synthesis.

***How to cite this article*:** Pervukhin D.A., Ilyushin Yu.V. A parallel analysis of hydrolithospheric beds geodata of narzan mineral water Kislovodsk deposit. Zapiski Gornogo instituta. 2016. Vol.221, p.706-711. DOI 10.18454/PMI.2016.5.706

Introduction. One of the central tasks in the course of mining mineral waters in the region of Kavkazskie Mineralnye Vody is keeping at minimum damage to the regional environment. That task is solved, first of all with the techniques of water treatment and principally new techniques of mineral water uptake. However, with progress in the technology of mineral water production the issue becomes more and more acute of finding optimal techniques to search for its new deposits. Until recently, such tasks were solve by geologists teams in the region of Kavkazskie Mineralnye Vody, such parties studying the northern part of the Main Caucasus Ridge. Later surveying the area for mineral water was carried out analyzing chemical composition of runoff of the rivers starting from the foothills of Mount Elbrus. That technique has its own drawbacks related to the fact that rivers are formed by an enormous number of sources and tributaries opening into them (consider for example river Kich-malka which has at least 96 tributaries, so that the chemical composition of its water keeps changing all the time). It makes pinpointing definitely the class of narzan (the mineral water of Kislovodsk deposit) and its location quite difficult.

To analyze chemical composition and temperature of water it is suggested to use unmanned aerial vehicles (UAV) that map the areas of our interest with aero-spectral photography [1-4]. Next such photographs are subjected to dedicated processing. Linear processing of photographs is complicated by lack of possibility to handle big data arrays with just the current level personal computers. That task may only be solved by multiprocessor multi-kernel systems, while to process such data with multiprocessor PC systems one needs to use extra expansion boards which makes such systems much more expensive. To save some of such cost it is suggested to employ the Nvidia CUDA (Compute Unified Device Architecture) technology to process geo-data from UAV.

Study technique. To process the data produced by UAV «Trimble» a dedicated SW application is available: a photogrammetric module, such as Trimble Business Center (TBC) [3]. To improve processing capacity of that application SW one needs to do parallel processing.

Meanwhile, to employ efficiently the technical capabilities of parallel processing calls for principally new approaches to organizing computations and programming of parallel distributed algorithms. In that case the tasks of modeling, analysis, synthesis and management of distributed systems may be implemented at the new qualitatively higher level using the techniques of parallelization of linear algorithms. Essentially they

DOI 10.18454/PMI.2016.5.706

consist in breaking the composite multipliers and terms into separate components looking as lines of a 2D and 3D data array. Next such lines of the newly formed multi-dimensional array are sent for processing to the arithmetic and logical device of multi-stream calculator. The number of lines of such a multi-dimensional array depends on the number of arithmetic and logical devices in the parallel processor.

Analyzing the depths of water sources from the data of aerial photography. Consider a specific example. The first block of data was taken from board the UAV«ZALA 421-04f». Data for analysis were provided by «Gasprom Space Systems» OJSC. The block consisted of 26 legs. The total number of picture in the block was 595. Top take pictures the «Canon EOS 500D» digital cam was used, calibrated in advance. Flight height over the terrain was about 500 m, single pixel size corresponding to approximately 8 cm distance on the ground. 25 reference points were measured and marked on the map of the area. Error margin of retrieving the coordinates of reference points did not exceed 10 cm. The total vertical drop of terrain elevation across the leg of about 3 km long reached 70 m.

The block of aerial photographs was processed in automatic mode following the simplified scheme without equalizing and using reference points. Spatial referencing was done using projection centers, separate pictures were transformed using the PHOTOMOD «GeoMosaic» application disregarding terrain relief. The following check of obtained ortho-photographic plans against the reference points has shown discrepancies at reference points exceeding 17 m. Such a low accuracy of ortho-photographic plan is due to both high vertical drop of the terrain and inaccuracy of measuring projection centers while the UAV is in flight.

Next the same block was subjected to strict photogrammetric processing Three of the measured reference points were used as control ones for equalizing. The RMS deviation of equalizing by reference points was 15; 16; 12 cm, and 23; 29 and 57 cm by control points, respectively. Deviations at linking points were 8; 14 and 69 cm.

It was found in the course of equalizing that the coordinates of projection centers contain a systematic error, its main component reaching 10.5 m by elevation. RMS errors at projection centers were 84; 239 and 75 cm after detracting that systematic error. Most probably, the considerably larger error along the flight direction is related to inaccuracy in identifying the moment of shooting start. Large errors at linking points are possibly related to cam calibration inaccuracies and error accumulated taking pictures with a camera with slit shutter. The largest errors at link points are found at frame edges and in their corners.

Further processing of the block followed the standard scheme. Terrain relief was plotted in automatic mode and then ortho-transformation of the pictures taken with the account of that relief.

To analyze the results an array of data to be processed was formed. The array has an enormous number of columns that consist of differential characteristics, their sums yielding the distance to to the studied object.

Below we cite the algorithm for calculating the depth and chemical composition of water sources. Such algorithm is rather easily reduced to parallel form. For that it is sufficient to sum all the elements of columns – layers.

To demonstrate the advantage of using the technology of parallel computing we offer two programs, one of them summing the elements following a simple linear algorithm, and the other executing a parallel algorithm as applied to the technology of hybrid computing, Nvidia CUDA [3, 4]. The linear programmed algorithm is written in the form:

```
for j := 1 to n do begin
for i := 1 to m do begin
s[j] := s[j] + a[i,j];
sum := sum + a[i,j]
end;
```

The code of parallel algorithm is presented in the form:

```
__global__ void add( int *a, int *b, int *c )
int tid = blockIdx.x;
if (tid < N)
c[tid] = a[tid] + b[tid];
sum := sum + a[tid]
```

DOI 10.18454/PMI.2016.5.706

It is seen from the presented program codes that the linear algorithm features two identifiers: i (the line) and j (the column). the parallel algorithm has that identifier set in the array tunings, while the identifier tid sets the number of data stream. Therefore, the first code shown forms a single stream of data that undergo the operation of summation. The parallel algorithm produces a group of blocks equal to the number of processor kernels for each of which parallel data arrays are formed. The programmed code for forming such groups of data looks like this [1, 2, 5, 6, 13]:

```
HANDLE_ERROR( cudaMalloc( (void**)&dev_a, sizeof( int ) ) );
HANDLE_ERROR( cudaMalloc( (void**)&dev_b, sizeof( int ) ) );
HANDLE_ERROR( cudaMalloc( (void**)&dev_c, sizeof( int ) ) );
```

Upon producing the programmed complex one needs to copy the data to the computing processor using the programming operator cudaMemcpyDeviceToHost to organize computations over the vector types of data:

```
cudaMemcpy( dev_a, &z, sizeof(int),cudaMemcpyHostToDevice );
cudaMemcpy( dev_b, &d, sizeof(int),cudaMemcpyHostToDevice) );
cudaMemcpy( dev_c, &k, sizeof( int ), cudaMemcpyHostToDevice );
```

Calling the computing module is done using the scheme with rigid link to the performer kernel:

```
add<<<1,N>>>( dev_t_mas , dev_z, dev_k1, dev_k2, dev_l, dev_a, dev_t_zad, dev_k, dev_d, dev_s);
```

It made possible the functioning of that module exceptionally on the first processor of the calculator in an unlimited number of streams (the principal difference between a graphic processor and a PC processor is that the graphic processor has hundreds of arithmetic and logical devices while the PC processor only has one). Changing the first parameter of the function one may run calculations on other calculators, provided they are available in the system. Also, combining such parameters one may produce programmed controls for high capacity systems based on NVidia tesla calculators. However, since tesla calculators feature four built-in processors of 2000 kernels each, one needs to calculate stream operations additionally. Therefore a possibility opens to do parallel processing of groups of data [8, 11] gaining higher productivity of computational media.

The results of analyzing aerial pictures of the Kislovodsk deposit taken from board UAV provided by the «Narzan» OJSC with the use of both techniques appeared to be identical to each other, however computer time spent on them was quite different: it took 15 min for the linear algorithm and 58 s for the parallel algorithm (State Registration Certificates on Computer SW Nos 2013661620, 2014613035, 2014613151). Note that while solving the task no extra computational techniques were involved, such as, e.g., the section technique, the variables separation technique or any others.

Analysis of temperature fields of hydrolithospheric seams. When calculating temperature fields, second order differential equations in partial derivatives are used. To solve that task the respective equation is presented in the form:

$$\frac{\partial T(x,y,z,\tau)}{\partial t} = a\left(\frac{\partial^2 T(x,y,z,\tau)}{\partial x^2} + \frac{\partial^2 T(x,y,z,\tau)}{\partial y^2} + \frac{\partial^2 T(x,y,z,\tau)}{\partial z^2}\right) + Q,$$

where T – temperature; t – time; a – the coefficient of temperature conductivity; τ – time increment; Q – the power output of internal heat sources.

Having calculated the temperature field on the basis of parallel synthesis algorithm [2, 4], we obtain a discrete analogue of the mathematical model. That discrete analogue of the mathematical model of temperature field is presented in the form of the equation

DOI 10.18454/PMI.2016.5.706

$$T(x,y,z,t)=a\Delta t\left(\begin{array}{l}\frac{T(x-1,y,z,t)-2T(x,y,z,t)+T(x+1,y,z,t)}{\Delta x^2}+\\ +\frac{T(x,y-1,z,t)-2T(x,y,z,t)+T(x,y+1,z,t)}{\Delta y^2}+\\ +\frac{T(x,y,z-1,t)-2T(x,y,z,t)+T(x+1,y,z+t,t)}{\Delta z^2}\end{array}\right)+Q.$$

Since a specific feature of the Kislovodsk deposit of Narzan is the presence of different types of Narzan in one and the same geographical location (sulfate, dolomite, common), one needs to calculate temperature fields for each Narzan seam. For that purpose we produce discrete analogues for three types of Narzan located one on top of the other [1, 2, 5-15]:

Sulfate

$$T(x,y,z,t)=a\Delta t\left(\begin{array}{l}\frac{T(x-1,y,z,t)-2T(x,y,z,t)+T(x+1,y,z,t)}{\Delta x^2}+\\ +\frac{T(x,y-1,z,t)-2T(x,y,z,t)+T(x,y+1,z,t)}{\Delta y^2}+\\ +\frac{T(x,y,z-1,t)-2T(x,y,z,t)+T(x+1,y,z+t,t)}{\Delta z^2}\end{array}\right)+Q;$$

Dolomite

$$T(x,y,z,t)=a\Delta t\left(\begin{array}{l}\frac{T(x-1,y,z,t)-2T(x,y,z,t)+T(x+1,y,z,t)}{\Delta x^2}+\\ +\frac{T(x,y-1,z,t)-2T(x,y,z,t)+T(x,y+1,z,t)}{\Delta y^2}+\\ +\frac{T(x,y,z-1,t)-2T(x,y,z,t)+T(x+1,y,z+t,t)}{\Delta z^2}\end{array}\right)+Q;$$

Common

$$T(x,y,z,t)=a\Delta t\left(\begin{array}{l}\frac{T(x-1,y,z,t)-2T(x,y,z,t)+T(x+1,y,z,t)}{\Delta x^2}+\\ +\frac{T(x,y-1,z,t)-2T(x,y,z,t)+T(x,y+1,z,t)}{\Delta y^2}+\\ +\frac{T(x,y,z-1,t)-2T(x,y,z,t)+T(x+1,y,z+t,t)}{\Delta z^2}\end{array}\right)+Q.$$

Next we provide the initial code of the program module that executes modeling itself. Note that the procedure starts with the announcement «global». The key word __global__ in the announcement and the function definition means that the function is executed on the graphic map, that function called up from the CPU. An unalienable attribute of such a function are the brackets <<< >>> when that function is called. The compiler nvcc splits the initial code into parts which are executed separately on the CPU and the GPU. The code generated for such functions is executed by the GPU as kernel:

```
__global__ void Cuda_proccedure(double ****dT)
for (r=1; r<=I-1; r++)
for (fi=1; fi<=30; fi++)
for (x=1; x<=1199; x++)
{ if ((r<5)||(r>8)) {a=22.16;}
else a=0.3769;
dT[r][fi][x][timer]=((T[r-1][fi][x][timer]-
2*T[r][fi][x][timer]+T[r+1][fi][x][timer])/r*r+(T[r][fi-1][x][timer]-
2*T[r][fi][x][timer]+T[r][fi+1][x][timer])/fi*fi+(T[r][fi][x-1][timer]-
2*T[r][fi][x][timer]+T[r][fi+1][x+1][timer])/x*x); }
```

DOI 10.18454/PMI.2016.5.706

The results of mathematical modeling of temperature fields using a supercomputer and a common PC are identical to the fifth decimal position, however the time spent on parallel computing using the respective algorithm is much shorter.

Results and discussion. Using unmanned aerial vehicles as aerial photographing platforms has a great future. Employing such unmanned aerial vehicles in conjunction with the Nvidia CUDA SW/HW platform with accelerate the rate of processing the data provided by such aerial photography. However, one should never forget that using the Nvidia CUDA technology only provides higher productivity in case parallel algorithms are used. When aerial photographs are taken over large areas, the Nvidia CUDA SW/HW technologies help to reduce considerably the time spent on calculating both elevation and depth characteristics due to simultaneous coverage of the array from several sides.

Productivity may also be improved via plotting the terrain relief in bi-directional mode. Since the HW architecture of Nvidia CUDA includes at least 96 arithmetic logical devices, that system is capable of supporting 96 directions of processing modes for bitmap images, minimum. Such quantity of arithmetic logical devices exists in the cheapest budget versions of graphic accelerators that support the Nvidia CUDA technology.

If one considers more expanded versions of that technology, graphic accelerators of the «Tesla» class may be used. Such accelerators are fitted with four processors of 2000 arithmetic logical devices each, their cumulative rate reaching 1 teraflop (1 Trillion operations per second). Using a graphic accelerator in a local PC makes it possible to build the elevation matrix for a map of a graphic object of 100 ha area in 6 s. Regular PCs take a day to do that job.

Conclusions

The following conclusions may be formulated on the results of this study.

1. The analysis of aerial spectral photographs using parallel algorithms has demonstrated considerable increase in the data processing rate, especially when calculating depths and analyzing chemical composition of the rivers. It gives a possibility of fast mapping of water seams across terrain.

2. The analysis of temperature fields from the photographs demonstrates that the process of heating is inhomogeneous in dependence of elevation above the sea level. Presumably, it is related to the presence of thermal sources, hence of hot dolomite and sulfate sources of Narzan in the foothills of the Main Caucasus Ridge.

3. Simulating these processes on a hybrid supercomputer has taken 10 min. A linear algorithm run on a common PC takes 6 hours to simulate such a process. High simulation rate is implemented mainly due to a 96-kernel processor operating at higher cumulative rate than a regular processor of a common PC [4,5].

The analysis of results of mathematical simulation indicates that the process of parallel analysis of data from seismic survey of hydro-lithospheric seams of mineral water may be accelerated quite noticeably with application of hybrid supercomputers. Their use would reduce considerably modeling of transitional characteristics.

REFERENCES

1. *Il'yushin Yu.V.*, *Pershin I.M.* Green function based technique of control of temperature field. Zapiski Gornogo instituta. 2015. Vol.214, p.57-70 [in Russian].

2. *Il'yushin Yu.V.*, *Trushnikov V.E.* Multithreaded analysis of seismic data on hybrid supercomputers. Gornyi informatsionno-analiticheskii byulleten'. 2015. N 5, p.230-235 [in Russian].

3. *Il'yushin Yu.V.*, *Trushnikov V.E.*, *Lyashenko A.L.* Developing and adaptive management system with distributed pi-regulator. Gornyi informatsionno-analiticheskii byulleten'. 2014. N 1, p.341-346 [in Russian].

4. *Il'yushin Yu.V.*, *Trushnikov V.E.* Designing pulse control of temperature field of drilling augers for mining hot mineral water of Kislovodsk Narzan deposit. Gornyi informatsionno-analiticheskii byulleten'. 2014. N 2, p.172-181 [in Russian].

5. *Ilyushin Yu.*, *Pervukhin D.*, *Afanasieva O.*, *Klavdiev A.*, *Kolesnichenko S.* Designing of Distributed Control System with Pulse Control. Middle-East Journal of Scientific Research. 2014. N 21 (3), p.436-439. http://dx.doi.org/10.5829/idosi.mejsr.2014.21.03.21433

6. *Ilyushin Y.* Designing of temperature field control system of tunnel kilns of conveyor type. Scientific-technical news of S.Pt.SPI. 2011. N 3 (126), p.67-72.

7. *Kolesnikov A.*, *Zarembo Ya.*, *Zarembo V.* Discharge of a Copper-Magnesium Galvanic Cell in the Presence of a Weak Electromagnetic Field. Russian Journal of Physical Chemistry. 2007. N 81 (7), p.1178-1180. http://dx.doi.org/10.1134/s003602440707031x

8. *Kolesnikov A.* Nonlinear Oscillations Control. Energy Invariants. Journal of Computer and Systems Sciences International. 2009. N 48 (2), p.185-198. http://dx.doi.org/10.1134/S1064230709020038

9. *Pleshivtseva Y.*, *Rapoport E.* The Successive Parameterization Method of Control Actions in Boundary Value Optimal Control Problems For Distributed Parameter Systems. Journal of Computer and Systems Sciences International. 2009. N 48 (3), p.351-362. http://dx.doi.org/10.1134/S1064230709030034

10. *Rapoport E.* Structural Parametric Synthesis of Automatic Control Systems with Distributed Parameters. Journal of Computer and Systems Sciences International. 2006. N 45 (4), p.553-566. http://dx.doi.org/10.1134/S1064230706040071

11. *Ilyushin Yu.*, *Pervukhin D.*, *Afanasieva O.*, *Klavdiev A.*, *Kolesnichenko S.* Solution of Problem of Heating Elements' Location of Distributed Control Objects. Global Journal of Pure and Applied Mathematics. 2016. Vol.12. N 1, p.585-602.

12. *Zarembo V.*, *Kiseleva O.*, *Kolesnikov A.*, *Burnos N.*, *Suvorov K.* Structuring of Inorganic Materials in Weak Rf Electromagnetic Fields. Inorganic Materials. 2004. N 40 (1), p.86-91. http://dx.doi.org/10.1023/B:INMA.0000012184.66606.59

13. *Ilyushin Yu.*, *Pervukhin D.*, *Afanasieva O.*, *Klavdiev A.*, *Kolesnichenko S.* The methods of the synthesis of the nonlinear regulators for the distributed one-dimension control objects. Modern Applied Science. 2015. Vol.9. N 2, p.42-61.

14. *Zarembo V.*, *Kolesnikov A.* Background Resonant Acoustic Control of Heterophase Processes. Theoretical Foundations of Chemical Engineering. 2006. N 40 (5), p.483-495. http://dx.doi.org/10.1134/s0040579506050058

15. *Kolesnikov A.*, *Zarembo Ya.*, *Puchkov L.*, *Zarembo V.* Zinc Electrochemical Reduction on a Steel Cathode in a Weak Electromagnetic Field. Russian Journal of Physical Chemistry. 2007. N 81 (10), p.1715-1717. http://dx.doi.org/10.1134/s0036024407100330

***Authors*: D.A.Pervukhin**, *Dr. of Engineering Sciences*, *Professor*, *pervuchin@rambler.ru* (*Saint-Petersburg Mining University*, *Russia*), **Yu.V.Ilyushin**, *PhD in Engineering Sciences, Associate Professor*, *bdbyu@rambler.ru* (*Saint-Petersburg Mining University*, *Russia*).

The paper was accepted for publication on 02 June, 2016.