High performance computing software package for multitemporal Remote-Sensing computations

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***Abstract*— With the huge satellite data actually stored, remote sensing multitemporal study is nowadays one of the most challenging fields of computer science. The multicore hardware support and Multithreading can play an important role in speeding up algorithm computations. In the present paper, a software package (called Multitemporal Software Package for Satellite Remote sensing data (MSP^{SRS})) has been developed for the multitemporal treatment of satellite remote sensing images in a standard format. Due to portability intend, the interface was developed using the QT application framework and the core was developed integrating C++ classes. MSP.^{SRS} can run under different operating systems (i.e., Linux, Mac OS X, Windows, Embedded Linux, Windows CE, etc.). Final benchmark results, using multiple remote sensing biophysical indices, show a gain up to 6X on a quad core i7 personal computer.**

***Keywords*— Huge remote sensing computations, QT, multicore, multitemporal, Speedup.**

I. Introduction

Environmental evolution, global change, geology, biophysics, hydrology, vegetation monitoring, agriculture and others similar earth science fields are actually based on satellite imagery and more than 40 biophysical indices (i.e., Land Surface Temperature (LST) [1-4], Thermal Inertia (TI) [5-7], emissivity (ε) [8], Normalized Difference Vegetation Index (NDVI) [9], Leaf Area Index (LAI) [10-15], atmospheric Water vapor (W) [16-19], Global Environmental Monitoring Index (GEMI) [20-22], Weighted Difference Vegetation Index [23-25], Soil Adjusted Vegetation Index (SAVI) [26-28], etc.). Conversely, the huge accumulated quantity of satellite remotely sensed data represents a real challenge for both software and hardware capability treatments [29;30]. The computer hardware industry has provided more computational power with computer systems containing multiple core processors. These last, connected to a single Central Processing Unit (CPU) are called MultiCores (MC). The software developers have reduced the computation time adopting the parallel programming philosophy. Thus, using numerous emergent techniques (i.e., multiprocessing, MultiTHreading (MTH) [31], OpenMP library [32], MPI library [33], etc.) In this paper, a software package based on a self developed framework has been built. The software package is called Multitemporal Software Package for Satellite Remote sensing data (MSP^{SRS}) and the framework is called Multitemporal Multithreading on Multicore Computations Framework (3MCF). This last, computes Remote Sensing (RS) algorithms using the Simultaneous MultiThreading (SMT) technique. MSP^{SRS} computes automatically whole RS databases in order to: i) avoid the memory overflow, ii) accelerate the execution with full and/or partial parallelization, iii) maximize the speedup, and iv) exploit the full hardware power. The MSP^{SRS} has been developed integrating most commune remote sensing algorithms [34]. The interface has been developed using QT C++ class library offering the possibility to compute automatically statistical parameters (with graph option) with storage capability in selected folders. The output can be a series of representative biophysical index images and/or statistical graphs. In our case, we have used: the Advanced Very High Resolution Radiometer (AVHRR) Global PAL data (20.6 Mb: 5004 columns x 2168 rows) to compute ten of the most commune biophysical indices.

II. The Multitemporal Software Package for Satellite Remote sensing data (MSP^{SRS})

The present paragraph aims to explain the structure of the multithreaded algorithms and the core framework architecture, which are used in the MSP^{SRS}. The multithreading technique is used to accelerate the algorithm computation time, whereas the interface format is used to facilitate the user interaction independently of the operating system and the hardware used.

A. The MSP^{SRS} layered Architecture

MSP^{SRS} consists on a modular or packaged application structure. Each module corresponds to a satellite with its possible and different sensors. In this paper, we have used the

AVHRR module with the Global PAL data to test the operability and performance of the proposed structure. Each package follows the architecture presented in Fig. 1.

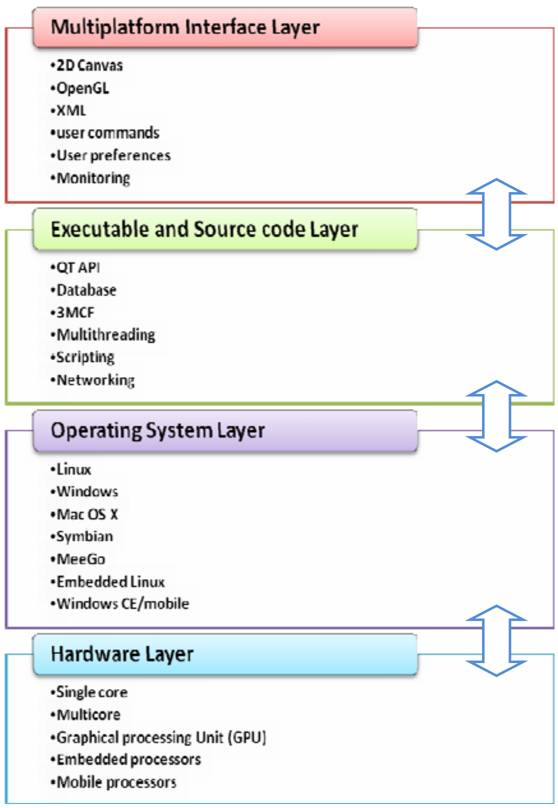

Fig. 1 Software architecture diagram.

The user interface accomplishes the user preferences and commands based on QT, 3MCF and some C++ classes. In order to be multiplatform, the interface is entirely written in XML language. Due to the C++ and QT [35] combination, the software package can run under different operating systems using different hardware architectures. In our case, we have mainly used: i) the 2D canvas to provide very fast or large scenes visualizations, ii) OpenGL library for building hardware-accelerated graphics and high performance visualization applications, iii) The ECMA standard scripting engine has been fully-integrated, iv) The Driver Layer provides support for ODBC, MySQL, PSQL, SQLite, ibase, Oracle, Sybase, DB2, v) The core provides the inter-object communications mechanism (i.e., File IO, Multi-threading and concurrency, event and object handling, Plugins, settings management, Signals and Slots). Based on a multithreading paradigm, the Graphical User Interface (GUI) monitors all executed jobs and schedules the temporal executions.

B. The core Framework: 3MCF

Designed for multithreaded implementation, the core framework is basically composed of C++ classes structured following the multiple layers architecture shown in Fig. 2. Due to portability intend, thread scheduling is given in part to the operating system with a high priority require.

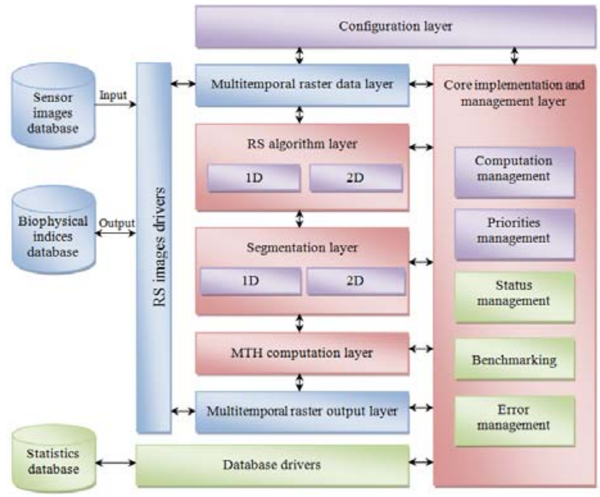

Fig. 2. Core framework architecture diagram.

The configuration layer permits an automatic computation of RS images. It is also responsible for the accomplishment of user preferences (i.e., maximum number of threads to execute over a CPU, thread priorities, the algorithm to be executed, RS database to compute, memory reservation depending on the number of images to be integrated in the corresponding RS algorithm). In this processing case, the threads are executed on the real time priority basis (e.g., highest possible priority). The core implementation and management layer is in charge of all computations executed over this framework. Default, preferences load RS images from the sensor-images database using the multitemporal raster data layer, and store the computed images (using MTH computation layer) in the biophysical-indices database using multitemporal raster output layer. The structure of sensor-images and biophysical-indices databases has been designed based on separating and storing the data within folders classed by years and months. This data, can be stored under different formats (i.e., Raster, Hierarchical Data Format, GeoTIFF, Erdas Imagine, Oracle Spatial GeoRaster, etc.) using RS image drivers layer. This last, is based on some developed file drivers and the Geospatial Data Abstraction Library (GDAL) [36]. RS algorithm layer regroups the most used algorithms subdivided in two categories: i) 1D algorithm section computes the biophysical indices requiring pixel by pixel computation (i.e., NDVI, GEMI, SAVI, etc.), and ii) 2D algorithm section computes the biophysical indices requiring multiple pixels by multiple pixel computation (i.e, W, LST, etc.). The framework computational approach is built up from a divide-and-conquer approach, by dividing the remote sensing image into regions and the algorithm application into multiples simultaneous threads. Instead of cropping the image into sub images with corresponding reserved memory, the segmentation layer has been structured on the basis of executing multiple threads on the original image itself which is already reserved in memory. This is defining high bandwidth parallelism and giving some high level degree of flexibility to RS algorithms needing neighboring pixel information. The segmentation layer has been developed taking in consideration the above mentioned concept with the following procedures.

1) 1D algorithm: symbolizing the principal algorithm format, it is constructed with simple mathematical operations between satellite bands or images.

```
For th=1 to n
Begin
    Sp = (th-1) * [(r*c)/n];
    Ep = th * [(r*c)/n];
    For k = Sp to Ep
      Begin
          Calculate the biophysical index
      End
End
```

with *th* the number of the executed threads, *Sp* and *Ep* are the start and end thread computing positions, *n* the total number of threads to be executed, *r* and *c* are respectively the total number of rows and columns of the image and *k* represents the physical memory address of the pixel to be used (in the RS algorithm) to compute a biophysical index.

2) 2D algorithm: The 2D algorithm segmentation is treated case by case with each own segmentation process. In this paper, we have used LST algorithm that involves W algorithm. This last is a 2D algorithm which segmentation procedure can be given by the following algorithm:

```
For th=1 to n
  Begin
    Sp = (th-1)*[(r*c)/n];
    Ep = th*[(r*c)/n];
    For k = Sp to Ep
        Begin
        I=k-i
        if ( I ≤ r*d ) or ( I ≥ r*(c-d) )
                Inexistent value for the biophysical index
    Else if ( I mod r ≤ d) or ( I mod r ≥ r-d )
                Inexistent value for the biophysical index
    else
        Calculate the biophysical index
    End if
  End
End
```

where *d* the maximum length of neighboring pixel needed in the algorithm and *i* the physical memory address of the first pixel in the image. The number of SMT, which is equal to *n*; can be defined by the user, by benchmark test, or by defect to the number of cores. In this paper, *n* has been set equal to *n*=(2,3,4,5,6,7,8,9,10,11,12,13,14,15,16) with the maximum value of *n*, $n_{(max)}$=16 corresponding to the double of the number of physical CPU used simultaneously (in our case the quad core Intel i7 with eight logical cores) with the aim of getting at least two periodical cycles.

III. Performance Analysis

To evaluate the performance of the 3MCF remote sensing software a SMT Remote Sensing Benchmarks (SMT^{RSB}) has been developed. The SMT^{RSB} is based on a process of running different RS based tests including RS algorithms and images. In this paper, a total number of 38400 tests of micro-benchmarks (e.g., 20 years x 12 months x 16 thread tests x 10 algorithms) have been considered. For accuracy commitment, the execution time counting in SMT^{RSB} has been set on milliseconds and microseconds based on two time referential counters. The different picked time positions are indicated in Fig. 3. t_S is indicating the start pick time directly after memory reservation, t_E the end pick time directly after file result saving, t_{SC} the start computation pick time indicating the start of running multithreaded RS algorithm and t_{EC} the end pick time computation just after ending of all the algorithms' parts computation and before file result saving.

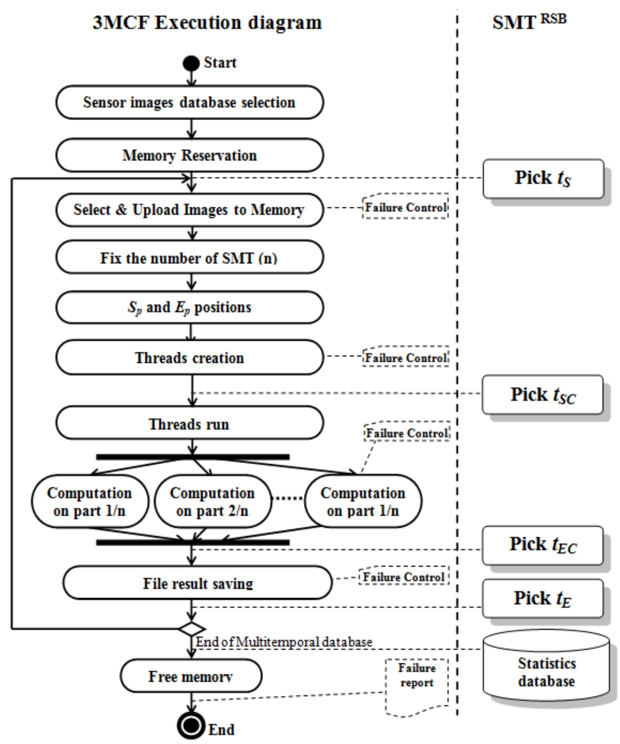

Fig. 3. 3MCF execution diagram and SMT^{RSB} picked time positions. t_S, pick time for start image computation, t_{SC}, pick time for start core computation, t_{EC}, pick time for end core computation, t_E, pick time for end image computation

A. Benchmarking Algorithms

In order to quantify the real time consumed for RS images computation, we have used the 10 commune remote sensing algorithms (see Table I). Subsequently, we have proceeded by picking recognized points (i.e., t_S, t_E, t_{SC} and t_{EC}) into the computation process (see Fig. 3.).

TABLE I
Remote sensing Algorithms

Algorithm	Cp	Author
$RVI = \frac{R}{NIR}$	1D	*Pearson and Miller 1972*
$NDVI = \frac{NIR - R}{NIR + R}$	1D	*Rouse et al. 1974*
$DVI = NIR - R$	1D	*Clevers 1986*
$GEMI = \eta(1 - 0.25\eta) - \frac{Red - 0.125}{1 - Red}$ $\eta = \frac{2(NIR^2 - Red^2) + 1.5NIR + 0.5Red}{NIR + Red + 0.5}$	1D	*Pinty & Verstraete 1992*
$MSAVI2 = \frac{2NIR + 1 - \sqrt{(2NIR+1)^2 - 8(NIR - Red)}}{2}$	1D	*Qi et al. 1994*
$Albedo = NIR + R$	1D	*Rao and Chen 1999*
$Emi = \varepsilon = \frac{\varepsilon_4 + \varepsilon_5}{2}$ $\varepsilon i = \varepsilon vi\ Pv + \varepsilon si\ (1-Pv) + Ci \quad (i = 4 \text{ or } 5)$ $Pv = \frac{(NDVI - NDVI_{min})^2}{(NDVI_{max} - NDVI_{min})^2}$	1D	*Raissouni and Sobrino 2000*
$DEMI = \Delta\varepsilon = \varepsilon_4 - \varepsilon_5$ $\varepsilon i = \varepsilon vi\ Pv + \varepsilon si\ (1-Pv) + Ci \quad (i = 4 \text{ or } 5)$ $Pv = \frac{(NDVI - NDVI_{min})^2}{(NDVI_{max} - NDVI_{min})^2}$	1D	*Raissouni and Sobrino 2000*
$W=0.26-14.253 \cos\theta \ln R_{54} - 11.649 (\cos\theta \ln R_{54})^2$ R_{54} = **Error!**	2D	*Raissouni and Sobrino 2000*
$LST = T4 + (1.4 + 0.32 (T4-T5)) (T4-T5) + 0.83 + (57-5W) (1-\varepsilon) - (161-30W) \Delta\varepsilon$	2D	*Sobrino and Raissouni 2000*

where Cp is the algorithm complexity, εsi and εvi are, respectively, the emissivities of bare soil and vegetation for AVHRR Channel i (i = 4 or 5), Pv is the proportion of vegetation, and Ci is a term that depends on the surface characteristics, R and NIR are images representing respectively the red and near infrared satellite channels, W is the total amount of the atmospheric water vapor using SW^{CVR} algorithm [37], ε and $\Delta\varepsilon$ are the effective emissivity and difference emissivity respectively [8].

IV. Performance Results

The execution time t_C (in seconds, s) for the multithreaded algorithm can be derived from the t_{SC} and t_{EC} pick times (see Fig. 3) using the following equation:

$$t_{(i)C} = t_{EC(i)} - t_{SC(i)} \qquad (1)$$

The average computation time have been carried out by averaging the 240 $t_{C(i)}$ values corresponding to 12 months of 20 years for the remote sensing biophysical index.

$$t_C = \frac{\sum_{i=1}^{240} t_{EC(i)} - t_{SC(i)}}{240} \qquad (2)$$

The results have been reported in Fig. 4 and have shown, that the number of cores in a multi-core chip has no effect when programming serial, on the other hand it is the most important criteria when programming parallel.

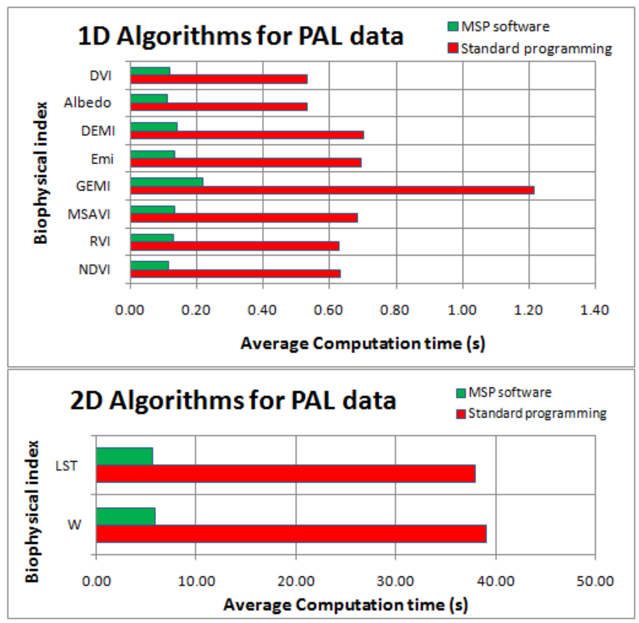

Fig. 4. MSP[SRS] and standard programming computation time

The SMP[SRS] software package chooses automatically the number of SMT to be used for the computation (SMT equals to the number of logical processing cores). The standard programming is an optimized C++ program not including parallelism techniques. With the aim of quantifying the gain in time comparing the serialized and parallelized programs; we have used the ratio of execution times called SpeedUp. It is given by the following equation:

$$\text{SpeedUp}(n) = \frac{t_{C(1)}}{t_{C(n)}} \qquad (3)$$

where n is the number of SMT, $t_{C(1)}$ is the iterative algorithm time or the running time corresponding to a unique thread and $t_{C(n)}$ is the time corresponding to the running time of a number of n simultaneous threads.

In order to quantify the potential of the developed 3MCF framework and MSP^{SRS}, a SpeedUp(n) with (n=1 to n=16) corresponding to a total number of 38400 tests of micro-benchmarks (applying the algorithms detailed in Table I) has been carried out. The SpeedUp has been obtained by averaging the 240 SpeedUp values corresponding to 12 months of 20 years. The SpeedUp results in function of the number of SMT (from 1 to 16) computed for the PAL data and ten biophysical indices (in Table I) have been reported on Fig.5.

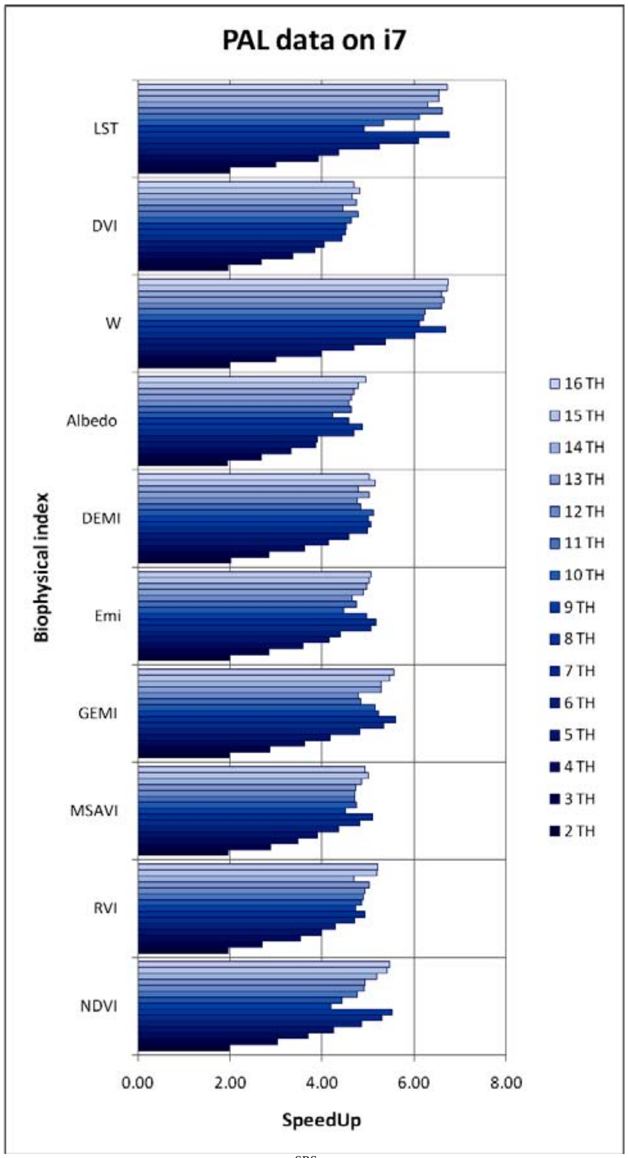

Fig. 5. MSP^{SRS} achieved speedup

Analyzing the results shown in Fig. 5, we have verified that the best speedup can be rapidly achieved with a number of SMT equivalents to the number of logical cores. For this reason, we have considered this last as the automatic pre-configuration criteria.

V. Conclusion

The potential of the developed Multitemporal Software Package for Satellite Remote Sensing data (MSP^{SRS}) integrating the self developed Multitemporal Multithreading on Multicore Computations Framework (3MCF) applied to Remote Sensing (RS) algorithms computations has been shown (in our case NDVI, RVI, DVI, Albedo, MSAVI, GEMI, ε, $\Delta\varepsilon$, W, and LST algorithms). The Multithreading on a multicore approach has potentially increases the multitemporal performance computing of the huge quantity of satellite remotely sensed data (in our case PAL data, with about 4 Terabyte).

The 3MCF was applied for a total number of 38400 benchmarks. Final results show a gain of 6X for the quad core intel i7 architecture.

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