11th. World Congress on Computational Mechanics (WCCM XI)
5th. European Conference on Computational Mechanics (ECCM V)
6th. European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

# COMPARATIVE STUDY OF PARALLELIZATION METHODS USING OPEN-MP AND MPI WITH AN UNSTRUCTURED RANS SOLVER FOR PRACTICAL APPLICATIONS

**Kunihide Ohashi[1*], Yohei Sato[2] and Takanori Hino[3]**

[1] National Maritime Research Institute, 6-38-1 Shinkawa Mitaka Tokyo Japan ,k-ohashi@nmri.go.jp
[2] Paul Scherrer Institute, Villigen PSI 5232, Switzerland, yohei.sato@psi.ch
[3] Yokohama National University, 79-5 Tokiwadai Hodogaya Yokohama Kanagawa Japan, hino@ynu.ac.jp

**Key words:** *OpenMP, MPI, Hybrid, RANS, Parallel computing*

Recently, RANS simulations are being applied to practical design problems, and the reduction of computational time is required to obtain many results for design trials. Processors are also remarkably progressing in year by year and most of CPUs have many cores in one architecture with large cache. There are two major ways of parallel computing, OpenMP and MPI. OpenMP uses stored data in shared memories without domain decomposition and communication across nodes, although it is limited to a single node. A computational domain is divided during pre-process and data is stored in distributed memories in case of MPI. Generally, MPI has an advantages in a large scale computing and it has already proved. Additionally, a hybrid method of OpenMP and MPI is effective when the communication across nodes consumes larger time as in case of using supercomputers. However, parallel computations are usually limited to a few nodes in a practical use.

A comparative study of parallelization methods using OpenMP, MPI and hybrid method in practical applications is carried out in the present study. An in-house unstructured CFD solver is used. The governing equations are 3D RANS equations for incompressible flows. Artificial compressibility approach is used for the velocity-pressure coupling. A cell-centered layout is adopted in which flow variables are defined at the centroid of each cell. Spatial discretization is based on a finite-volume method and inviscid fluxes are evaluated by the second-order upwind scheme based on the flux-difference splitting of Roe. The evaluation of viscous fluxes is also second-order accurate. The linear equation system is solved by the symmetric Gauss-Seidel (SGS) method, and the multi-color Gauss-Seidel method(MCGS)[1] is employed in case of OpenMP to avoid the data race condition. Agglomeration multigrid method is adopted for the fast convergence. Domain decomposition is achieved by using METIS for MPI and hybrid method. Data communications on MPI are required several times to set the boundary conditions in one time step and in each Gauss-Seidel iteration to syncronize the solutions of neighboring domains. All the computations are carried out on the SMP cluster with Intel Xeon E5-2680(2.7GHz, 8 cores), 64GB memory and 1GbE for communication.

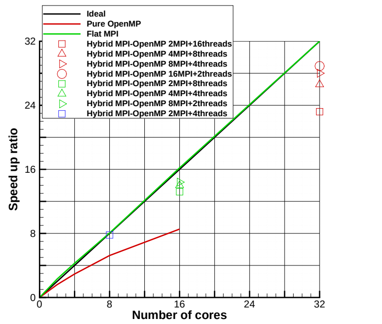


**Figure 1**: Speed up ratio of case1

At first, a flow computation around 2D flat plate is carried out (case1). The computational grid consists of 97,000 cells. Almost 2% cells are the domain-decomposition boundary cells (communication cells) in case of 32 decompositions. The speed up ratio of MPI is excellent and shows the ideal performance. The result of OpenMP is less efficient than MPI. The iteration process of MCGS with fewer cells in each color may spend more time. The results of hybrid method is also less efficient than MPI results. The speed up ratio is improved with the increase of the number of MPI processes and the decrease of the thread number of OpenMP.

Next, the flow around a practical hull form is computed (case2). The computational grid has about 900,000 of cells and 25% cells are communication cells in case of 32 domain decomposition. The results of OpenMP show better performance than the results of case1. The number of cells in each color of MCGS increases and the time for iteration process is relatively decreasing. Although the speed up ratio of MPI shows a good performance up to 8 processes, the ratio gradually deviates from the ideal. The data communication requires longer time due to the larger number of communication cells. The hybrid method shows a good performance with 2 MPI processes and 16 threads. OpenMP with shared memories succeeds to reduce the data communication on the hybrid method.

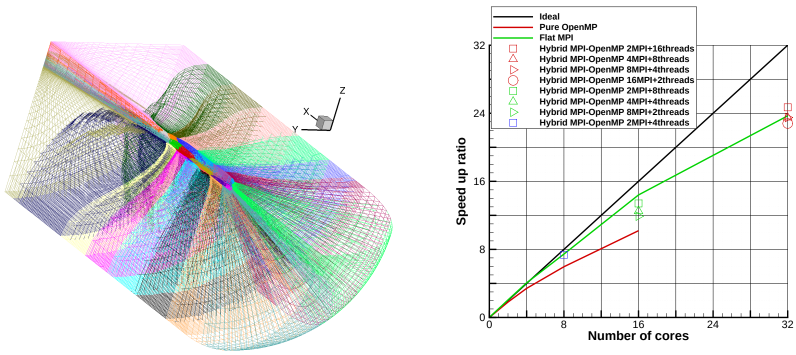


**Figure 2**: Computational grids of 32 parallel MPI and speed up ratio(case2)

Finally, the following conclusions are addressed. OpenMP with the MCGS method shows better performance with fixed amount of cells in each color and the hybrid method shows a good performance in case data communication load is heavy. At most 10% of all cells for data communication cells is preferable for the flat MPI method in the present study.

## REFERENCES

[1] Y. Sato. T. Hino. K. Ohashi. Parallelization of an unstructured Navier-Stokes solver using a multi-color ordering method for OpenMP. *Computers & Fluids*, Vol.**88**, 496-509, 2013.