A Dynamic Load Balancing Strategy For Real-Time Aircraft Collaborative Simulation

J.X.Zhao
National CIMS Engineering Research Centre
Tsinghua University
P.R.China
Shanghai Aircraft Design and Research Institute of the Commercial Aircraft Corporation of China Ltd
P.R.China

G.Z. Peng
National CIMS Engineering Research Centre
Tsinghua University
P.R.China
Shanghai Aircraft Design and Research Institute of the Commercial Aircraft Corporation of China Ltd
P.R.China

H.M. Zhang
National CIMS Engineering Research Centre
Tsinghua University
P.R.China

***Abstract*--Synergic collaboration and load balancing are important techniques for complex aircrafts system simulation. The synergic models included aerodynamic, atmospheric and engine control models are studied and categorized into two groups in this paper. Moreover, optimizing the dispatch strategy is an essential approach to manage the complex tasks of aircraft simulation. A fading memory strategy using least squares method is proposed to solve the information aging problem and the binary-tree hierarchical organization based on the periodical feature with the proposed strategy is adaptive for the aircraft simulation.**

Keywords-dynamic load balancing; migration strategy; aircraft simulation; real-time

I INTRODUCTION

Aircraft dynamics simulation is a complex nonlinear process whereby engine, aerodynamic and atmospheric models are solved simultaneously [1]. Optimizing the dispatch strategy is an essential approach to manage the complex tasks of aircraft simulation. To meet the real-time requirement demanded by interactive simulations, one of the scheduling strategies is balancing the load in the simulation execution and providing fault-tolerance capability [2].

Load balancing is proposed for avoiding excessive resources consumption peaks in a simulation system, such as the system has the set of all computational simulation nodes and network components involved in an event. Several load balancing mechanisms have been proposed for a wide variety of distributed applications, which can be categorized into two groups: manual and dynamic load balancing. Manual load balancing is a front-loaded strategy where potential performance peaks are anticipated and the initial system is configured in a way that is hoped to produce minimal resource consumption peaks before the start of a simulation event. Therefore, the manual load balancing strategy is inexact and inefficient for highly simulation performance [3]. Dynamic load balancing techniques are required to migratesimulated entities transparently and obviate to interrupt the timing of event distribution or timely response to simulation events. Reiher and Jefferson proposes a time warp dynamic policy based on the effective utilization of processor [4]. Glazer and Tropper present a simulation advance rate of its simulation clock as a function of the amount of CPU time for time warp parallel simulation [5]. Jiang et al. proposes a dynamic load balancing algorithm to reduce the number of rollbacks and thus increase the total simulation speed [6]. A recent paper by Cai et al. describes a load management system for HLA-based distributed simulations over the grid [2].

Due to the logically model building process of aircraft simulation, the dynamic load balancing mechanism with federate migration strategy is fit for our research where entities and logical process are at the same space. This paper is focused on the load balancing strategies, aiming to improve the dynamic algorithm and apply to aircraft collaborative simulation.

II COLLABORATIVE SIMULATION MODEL

The design and development of complex aircraft systems involves multiple disciplines such as aerodynamic and atmospheric models and engine control, and the collaborative approach becomes an essential tool [7]. The synergic collaboration of multidisciplinary computational models involves the exchange of simulation data generated in parallel at runtime from the numerical integration processes of these models as shown in Figure 1 which can be divided into real-time and non real-time parts.

As an essential technical approach to manage the complex synergic collaboration processes, the load balancing involves three aspects, load monitoring, migration policy and priority scheduling [8]. Load monitoring is a complicated task which seeks to define an entity-independent measure of simulation load on a per-entity basis. And the priority scheduling has classic strategies to fit various systems.

The migration policy is a basic technique of load balancing which requires an identification of the state data that could be captured, communicated and used to instantiate a clone of a running simulation implementation. The load balancing structure of collaborative simulation is in Figure 2.

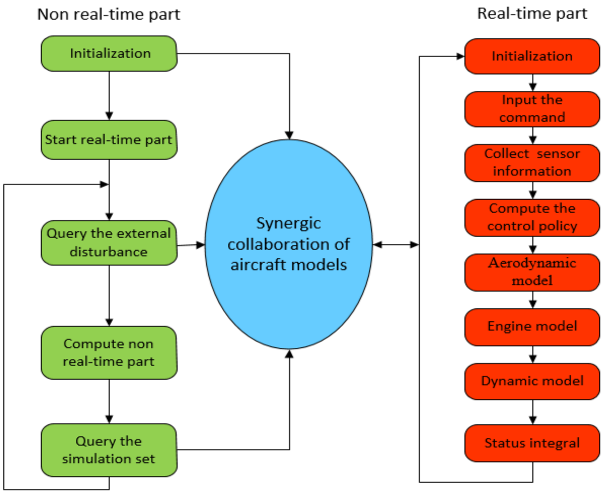

FIGURE I. THE NUMERICAL PROCESSES OF AIRCRAFT COLLABORATIVE SIMULATION.

III MIGRATION STRATEGY

In order to facilitate federate execution, the research focuses on migration strategy in aircraft simulation. The migration policy is usually taken into consideration in real-time collaborative simulation since the data-output israndom and variable. Trying to find out the relationship between the migration threshold and computation times, the federate migration policy exceeded the threshold can be built.

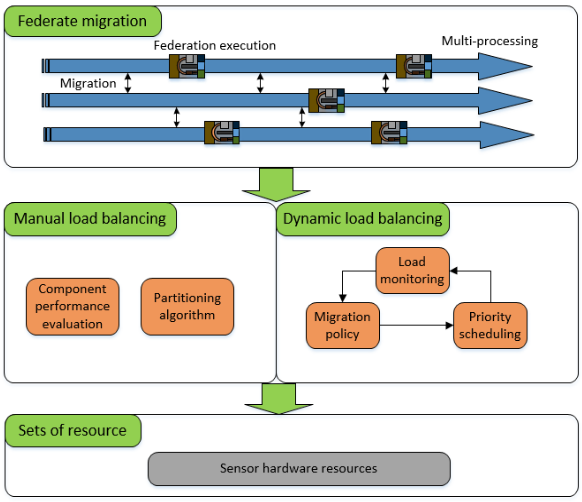

FIGURE II. THE LOAD BALANCING STRUCTURE OF COLLABORATIVE SIMULATION.

The least squares method is used to find the parameters of the system and the parameters are gained for computing the threshold. However, the classic least squares method can only solve the static system. Thus the method focused on dynamic system is recursive where the original parameters are revised according to the new data in order to get the improved estimates instead of mixing the new and old data together. In addition, the new data reflected the load-balanced status should be paid more attention rather than take all the data equally. On the basis of this consideration, fading memory strategy is adopted to refresh the load index where the old data will be forgot with the data accumulation. The load index is defined as

$$J = \sum_{k=n+1}^{n+N} \rho^{n+N-k} [y(k) - \varphi_{k-n}^T \theta]^2, 0 < \rho < 1 \quad (1)$$

Where ρ is the weighted coefficient and $\rho < 1$ means the older the data is, the less the weight is and the smaller the influence is. On the other hand, the new data will play a more important role as the newest data has $\rho = 1$. In aircraft simulation, $\rho = 1 - \frac{1}{N}$ is chosen to get the value of ρ. $y(k)$ is the output of each federate at the time of k, and the error is $e(k)$, we have the formula as follows

$$y(k) + \sum_{i=1}^{n} a_i y(k-i) = e(k) \quad (2)$$

$$\varphi_{k-n}^T = [-y(n+k-1), \ldots, -y(k)] \quad (3)$$

$$\theta^T = [a_1, a_2, \ldots, a_n] \quad (4)$$

The residual sum of squares with the weighted parameter can be obtained from the process above, that is, the load index J can be represented. Once the load index exceeds the threshold set in advance, the federate will start migration. The migration algorithm with fading memory strategy is shown in Figure 3 and this algorithm is workable in the real-time simulation of aircraft experiment.

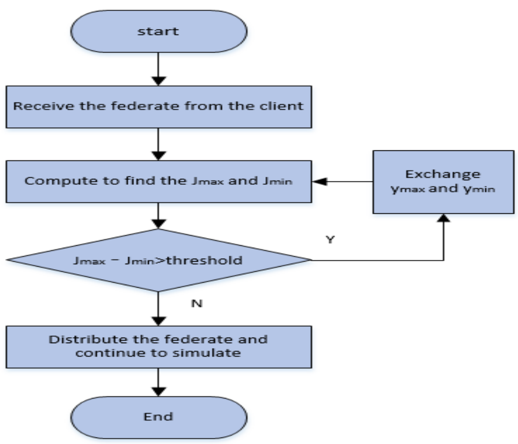

FIGURE III. THE MIGRATION ALGORITHM WITH FADING MEMORY STRATEGY

IV STRATEGY IMPLEMENTATION

Considered the collaborative model of aircraft, the simulation rate of variety tasks is different at the basis frame. Most of real-time tasks are periodical during the simulation, that of the number of the maximum common multiple is chosen to be the basis period. Thus the real-time tasks of the simulation become a binary-tree hierarchical organization. The periodical tasks with the basis, double and fourfold frame period are named full rate module, 1/2 rate module and 1/4 rate module, respectively [9]. Meanwhile, the dynamic load balancing can be executed hierarchically which was described by Marc H. and Anthon P. [10].Taking the advantage of the hierarchical balancing scheme, the tasks of aircraft simulation composed by binary-tree is illustrated in Figure 4.

Aerodynamic module, engine module and engine module are all full rate modules at the top level and the processor of these modules complete 4 times iterations at one period. GPS module, air traffic control module and other similar management modules are at the second level which means they execute twice at one period. Moreover, the basic facilities supplement modules such as hydraulic pressure and atmospheric systems are at the bottom level since they just run once at any frame of the basis period contained four frames. The hierarchical balancing scheme functions asynchronously. All load levels are initialized by the load information which is sent from each processor. The leaf node and subtree load information are obtained at intermediate-nodes. If load imbalances occur at the same level, the migration will be executed at that level. If the load imbalance at different levels is greater than the preset threshold, one domain is considered overload and the migration will occur with domain nodes.

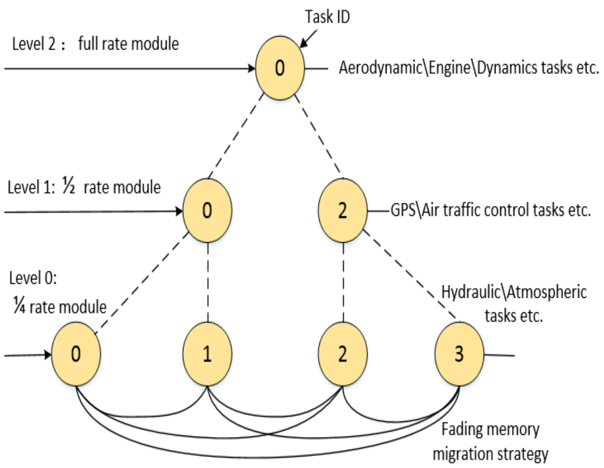

FIGURE IV. THE BINARY-TREE HIERARCHICAL ORGANIZATION WITH FADING MEMORY STRATEGY

All the processors with tasks in the aircraft simulation are responsible for the load balancing according to the hierarchical scheme. Both the local imbalances as well as excessive global imbalances are adaptive with the hierarchical organization. It is effective to preset different thresholds specified at different levels of the tree. In addition, the fading memory strategy is more accurate under the consideration of information aging problem.

V CONCLUSIONS

In this paper, the synergic collaboration models and load balancing strategies are studied for their applications to the real-time simulation of aircraft. The synergic models included aerodynamic, atmospheric and engine control models can be divided into two parts, real-time and non real-time. The migration strategy, as an essential part of load balancing, become our research focus. A fading memory strategy using least squares method is proposed to solve the old data refreshment problem. And the real-time tasks of the simulation become a binary-tree hierarchical organization based on the periodical feature. The proposed migration strategy is adaptive for the hierarchical aircraft simulation. The improvement and performance of the proposed strategy will play an important role in our future work.

ACKNOWLEDGMENTS

This research is supported by Shanghai Aircraft Design and Research Institute of the Commercial Aircraft Corporation of China Ltd (Grant No. 20124060179), the National Natural Science Foundation of China (Grant No.61374163) and the National Defense Pre-Research Foundation of China (Grant No.FZ1301).

REFERENCE

[1] Stevens, Brian L., and Frank L. Lewis, Aircraft control and simulation. Vol. 2. New York: Wiley, 2003.

[2] Cai, Wentong, Stephen John Turner, and Hanfeng Zhao. "A load management system for running HLA-based distributed simulations over the grid." Distributed Simulation and Real-Time Applications, 2002. Proceedings. Sixth IEEE International Workshop on. IEEE, 2002.

[3] White, Eric and Michael Myjak, "A Conceptual Model for Simulation Load Balancing." Proceedings of the 1998 Spring Simulation Interoperability Workshop, Vol. 21. 1998.

[4] Reiher, Peter L., and David Jefferson, "Virtual time based dynamic load management in the time warp operating system." Transactions of the Society for Computer Simulation, vol.7, no.2, pp. 91-120, 1990.

[5] Glazer, David W., and Carl Tropper, "On process migration and load balancing in time warp." Parallel and Distributed Systems, IEEE Transactions on, vol.4, no.3, pp. 318-327, 1993.

[6] Jiang, Ming-Ru, Shiuh-Pyng Shieh, and Chang-Long Liu. "Dynamic load balancing in parallel simulation using time warp mechanism." Parallel and Distributed Systems, 1994. International Conference on. IEEE, pp. 222-227, 1994.

[7] Silü L, Heming Z, Hongwei W. "Combinative algorithms for the multidisciplinary collaborative simulation of complex mechatronic products based on major step and convergent integration step." Chinese Journal of Mechanical Engineering, vol. 24, no.3, pp: 355-363, 2011.

[8] Kameda H, Li J, Kim C, et al. Optimal load balancing in distributed computer systems. Springer Publishing Company, Incorporated, 2011.

[9] Shutao Zheng. The flight simulator real-time simulation management system research. Harbin Institute of Technology, 2009.

[10] Willebeek-LeMair, Marc H., and Anthony P. Reeves. "Strategies for dynamic load balancing on highly parallel computers." Parallel and Distributed Systems, IEEE Transactions on 4.9, pp: 979-993, 1993.