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Preliminary Discussion on the High Performance Adaptive Analysis for Numerical Computational Method

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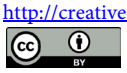

Abstract

Numerical computation is one of the reliable ways to solve partial differential equations. In the past three decades, with the rapid growth of computer processing power and storage space, numerical computation has been successfully applied to many fields. It provides strong support for researchers to solve complex engineering practical problems and analyze complex physical phenomena. Most of the existing numerical methods are element-based, among which the finite element method is the most famous. Modern numerical analysis technology is developing towards high efficiency, high accuracy, low cost and high performance, while the traditional analysis technology has been unable to meet the requirements. The first step in industrial manufacturing is engineering design, and the most basic tool of engineering design is calculation and analysis software, and calculation method is the most critical core problem in calculation and analysis software. At present, the software industry of our country is almost completely monopolized by foreign software products. The serious lack of domestic computing simulation software with completely independent intellectual property rights will surely become the biggest weakness in the implementation of the intelligent manufacturing 2025 in China. The research and development of advanced core adaptive computing methods and analysis technology with completely independent intellectual property rights play an important role in improving the development level of engineering analysis software in China and cultivating the ability of independent research and development.

Subject Areas

Mechanical Engineering

Keywords

Adaptive Analysis, Numerical Computation, Error Estimation, Finite Element Method

1. Introduction

As the engineering problems become more and more complex, the number of discrete models to be calculated by numerical methods is becoming larger and larger, for example, the number of nodes of Airbus A380 model is more than 100 million, and the number of elements is even larger, which directly causes the calculation time to be too long, and is not conducive to the analysis and optimization of products in the early stage of engineering. In order to solve this problem, with the existing hardware resources, it is necessary to develop an efficient and high-precision numerical method to analyze engineering problems, which not only improves the calculation accuracy, but also takes into account the calculation efficiency, so as to guide the direction of engineering improvement and optimization. However, the discrete model based on uniform mesh size is difficult to accurately analyze the high gradient region where the field variables change violently. In order to obtain higher solution accuracy, the mesh size can only be continuously reduced. The analysis of complex engineering problems has been greatly limited [1] [2]. In this case, researchers put forward the concept of adaptive numerical analysis, and quickly attracted widespread attention in academia.

2. Adaptive Analysis

The adaptive analysis technique guides the refinement of the grid in the region of high gradient variation of field variables by estimating the error of some intermediate results of numerical methods, while the grid in the region of low gradient variation of field variables is relatively sparse, and this intelligent grid arrangement can improve the computational efficiency as far as possible on the premise of ensuring high accuracy [3]. It is an effective way to improve the efficiency and accuracy of numerical methods by obtaining the most satisfactory calculation accuracy through the minimum calculation cost. A complete adaptive analysis process is an asymptotic process, which usually requires a multi-step calculation process, in the continuous iteration process, to obtain an infinite approximation to the real error distribution of the optimization discretization, so that the solution accuracy and efficiency are significantly improved. It will become the key technology of simulation and modeling in future engineering analysis system [4].

Adaptive numerical analysis method is to control the process of solving partial differential equations according to some intermediate calculation results of numerical methods, it automatically selects the optimal grid discretization mode

needed according to the intermediate calculation results, so as to gradually adjust the error automatically to achieve the desired accuracy, through the control of the calculation process of solving partial differential equations. The purpose is to obtain the highest possible calculation accuracy with the least calculation cost. The research contents of adaptive numerical methods mainly focus on adaptive strategy, error estimation and mesh generation, which directly determine the correctness and efficiency of adaptive analysis. In the numerical simulation analysis of engineering structures, in order to obtain the numerical solution as high as possible accuracy, analysts will refine the distribution of grids and nodes in the regions where there are large stress gradients or singularities in the analysis structure. In the process of analyzing complex engineering problems, it is difficult for analysts to grasp the real stress distribution law of the problem accurately by virtue of their personal experience in advance. Under the premise that the exact solution cannot be obtained, adaptive analysis based on error analysis can obtain the numerical solution as high as possible by consuming the minimum calculation cost.

3. Adaptive Strategy

The basic idea of the adaptive numerical analysis method is that in the high error regions with high stress concentration or high gradient, the Mesh density should be higher by increasing the number of nodes. a balance point should be found for the grid density, and too dense grid will consume a lot of computational resources, which will lead to high computational cost; But the grid density is too sparse, which leads to the accuracy of the calculation results cannot meet the requirements. For many complex engineering problems, it is difficult to accurately locate the stress concentration position by experience, so it is necessary to automatically adjust the grid density distribution according to the results of error analysis, and constantly improve the accuracy of the solution. Adaptive analysis can be divided into H-type, P-type, R-type and Hybrid-type four methods according to the specific implementation strategy [5].

3.1. H-Type

This method is based on the result of the error analysis of the last step, by adding nodes directly to the high error area in some way, the mesh is refined step by step to reduce the size of the element to achieve the purpose of adaptive mesh, improve the accuracy of solution, and make the calculation results approximate to the exact solution without changing the order of the element shape function. This method is simple, intuitive, easy to program implementation and has high reliability and stability, which makes the method become the most widely used method, this paper uses this method.

3.2. P-Type

The p-type method is quite different from the h-type method in that neither the

size of the computational mesh nor the locations of the nodes need to be changed. The accuracy of the solution is improved by elevating the order of interpolation function of each element and increasing the degree of freedom in the area where the computational accuracy is insufficient. Therefore, the elevation operation can be simply understood as adding new rows and columns to the original matrix equation to obtain a new matrix equation. Under the premise of a certain number of mesh elements, the p-type refinement method can quickly achieve the desired solution accuracy. Although this method is not as intuitive and easy to understand as the H-method, it saves a lot of time to regenerate mesh than the H-method, and its convergence efficiency is usually better than the H-refinement method.

3.3. R-Type

R-type method not only does not need to increase the number of nodes, but also does not need to change the order of the element shape function, keeping the number of nodes and elements unchanged. Usually, the nodes are moved to larger error regions, so that the discrete error is optimized, but this method of solution accuracy is very limited, after all, the number of nodes and elements is fixed in the beginning. For the initial sparse grid, it is difficult to obtain high accuracy solution by changing the location of the nodes to optimize the grid, but for the dense grid, when the number of nodes is relatively large, using r-method can optimize the grid without changing the degree of freedom of nodes, which can effectively improve the solution accuracy.

3.4. Hybrid Type

Usually, it is h-p combination method and r-p combination method. The H-P combination method is to increase the order of the shape functions of the elements while changing the grid size in the regions with large errors. The r-p combination method improves the order of the shape function while moving the position of the node. The H-p combination method is a commonly used combination encryption method. This method fully absorbs the advantages of the H-method and the p-method. The H-method is used in the region near the singular points, while the p-method is used in the region with smooth gradient. Although the H-P combination method is the most advanced method, which can not only achieve high convergence efficiency, but also has many good properties, it is difficult to apply to some simple problems.

4. Conclusion

In this work, we introduce the background of adaptive analysis of numerical methods, the basic concepts and theories of adaptive theory, adaptive strategy and error estimation. Whether a new numerical method is suitable for adaptive analysis has become a basic content of evaluating the merits of the numerical methods, so adaptive analysis is an indispensable part of meshless methods

based on point interpolation. Finite element adaptive analysis based on unstructured meshes has been relatively mature through the development for many years, but there are few major breakthroughs in recent years. Compared with the adaptive finite element method, the adaptive analysis of meshless methods is still a research field worthy of in-depth discussion. At present, domestic and foreign researchers mainly use finite element method or meshless method to carry out stress analysis in practical engineering, analysts need to consider the distribution of grid elements or background elements at all times, which will directly affect the accuracy of the numerical solution. Therefore, the experience of the analyst is very important in order to obtain the solution with high accuracy and minimum computational cost. Adaptive analysis technology is one of the ideal ways to solve this contradiction, it can use the computer to replace the analyst to automatically optimize the cell density distribution.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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