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Flexible distributed heterogeneous computing in traffic noise mapping

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ABSTRACT

In China, fast city rebuilding poses the challenge of frequent refresh cycle of urban traffic noise mapping. Computational complexity and lack of resources are the primary bottleneck in traffic noise mapping. In this paper, we present a flexible distributed heterogeneous computing method based on GPU-CPU cooperation, which reduces the overhead, improves the efficiency of parallel computing and consistently generates good quality results for traffic noise mapping. A genetic algorithm based large-scale task partition algorithm is employed to solve load balancing problem in distributed noise mapping calculation. The methodology is evaluated by an example, whose results show that the proposed task partition method can significantly improve running efficiency. Parallel efficiency increases from 54% to 78%. In addition, test speed is further improved by 21% with the GPU-CPU collaborative computing, even with only low-end type GPUs.

1. Introduction

The rapidly expanding traffic network worldwide has been increasingly recognized as a major contributor to the global biodiversity crisis, with traffic noise pollution (Nega, Smith, Bethune, et al., 2012). The Chinese government has made significant progress in urban traffic noise mapping in recent years. Strategic noise mapping research is conducted in some major cities in China, for instance, Beijing (Li, Feng, & Liu, 2012), Guangzhou (Cai, Zou, Xie, et al., 2015) and Hong Kong (Law, Lee, Lui, et al., 2011). Strategic noise mapping and its correction calculation is a typical computationally intensive task, usually consuming a large amount of computational time and resources.

With fast urban development in China, more frequent refresh cycle of noise mapping is required, leading to a negative impact on computing resource utilization. To improve the residents' quality of life with the fast building of skyscrapers, the demand of 3D noise mapping is strong. A lot of building facade noise calculation tasks and space slice grid calculation tasks are proposed from local authorities. "Dynamic Noise Mapping" technology becomes attractive, but local authorities suffer from a lack of modern infrastructure of high performance computers.

In this paper, we present a flexible distributed heterogeneous computational method which reduces the overhead, improves the efficiency of parallel computing and consistently generates good quality results for noise mapping. Our work focuses on the noise mapping collaborative computing on both CPU and GPU (Graphics Processing Unit), and presents a GA (Genetic Algorithm) based large-scale task partition algorithm to solve load balancing problem in distributed noise mapping.

In our system, commercial strategic mapping software packages are replaced by an independent-developed calculation kernel on both CPU and GPU. One of the reasons for using in-house noise prediction software is that commercial strategic mapping software may not be readily attainable for local authorities with limited budgets and resources (King & Rice, 2009). Furthermore, almost all commercial strategic mapping software packages are closed for developers, and they do not support running on heterogeneous computing environment. Although most commercial noise prediction software packages support parallel computing or distributed computing, the computing process management is not flexible and noise mapping solving mechanism is non-transparent. To our knowledge, no noise mapping software can support running on GPU at this moment. This situation is in deep contrast with GPU usage in the rest of scientific computation fields, as numerical weather prediction (Michalakes & Vachharajani, 2008) or computational fluid dynamics (Elsen, Legresley, & Darve, 2008). Noise mapping can be done with GPU to speed up the calculation process without any unacceptable increased cost. Our objective is to build a cross-platform noise mapping heterogeneous calculation kernel with same algorithm adopted both by GPU and CPU to ensure the accuracy of noise mapping results.

Another objective in this paper is to improve the calculation efficiency by using GA based task partition method, which could be done if we are able to measure noise mapping calculation cost by rule and line.

The rest of the paper is organized as follows: Section 2 provides a survey of current software patterns and an overview of parallel

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computing of noise mapping. Section 3 shows an implementation of heterogeneous computing platform based on CPU and GPU. Section 4 presents a genetic algorithm based calculation task partition method for load balancing problem in heterogeneous computing. In Section 5, our methodology and platform are demonstrated with a real noise mapping problem, with a comparison between the performances of traditional parallel computing and flexible distributed heterogeneous computing. Section 6 summarizes the conclusions.

2. Related work

Nearly all of the literatures about traffic noise mapping software covered the follows: improvement of computational accuracy and calculation speed, friendly GUI and highly flexible architecture, convenient data management and cutting software computational cost.

King and Rice (2009) proved the possibility of developing a simplified alternative to using detailed commercial software for the creation of strategic noise maps. They illustrated the cost benefits of in-house software and presented a hybrid approach to develop a strategic noise map by integrating measurements taken on-site with predictions.

Cho, Jin, and Manvell (2007) introduced a system to produce a noise map using noise and GPS data measured simultaneously. Their article focuses on data collecting, data storage and data processing in noise mapping.

Asensio, Recuero, Ruiz, et al. (2011) proposed a self-adaptive method for noise mapping grid generation. Their methodology adds new receivers to the sampling grid in those locations where they are expected to be more useful. This strategy can optimize the quality of the noise map at a really low additional computational cost. It is interesting to note that this self-adaptive methodology can be integrated into our calculation scale estimation model seamlessly.

Based on ASJ Model-1998, Bhaskar, Chung, and Kuwahara (2007) developed a noise mapping calculation kernel, named DRONE. The most noteworthy feature of the software is that DRONE involves integrating a road traffic noise prediction model with a traffic simulator to generate noise maps. The digital terrain model is one the most influential elements of computing accuracy and calculation speed in any large-scale noise mapping projects. Arana, Martín, and Nagore et al. (2011) have pointed out the accurate assessment of digital terrain data is an intricate but vital process. The conclusion of their paper is that computing with a 0.5 m degree of accuracy in elevation is sufficient for noise mapping and in contrast, computing with 5 m accuracy in elevation is insufficient. The work of this paper is very helpful to improve calculation speed in large-scale noise mapping.

Wang and Kang (2011) have pointed out the noise distribution in the cities in far east with large population is rather different from typical low density European cities. In their research, urban morphology on the traffic noise distribution patterns will lead to considerable effects in noise mapping. Thus, in recent years, many countries in the world are developing their own engineering models for predicting environmental noise levels, which are suitable to their own circumstances. In China, a new version of Technical Guidelines for Noise Impact Assessment is being updated.

Generally speaking, the prediction model is open to different interpretations when converting the engineering model to prediction software or noise mapping software. A lot of work focuses on model interpretations, like implementation of the Harmonoise (Erwin & Stapelfeldt, 2007; Defrance, Salomons, Noordhoek, et al., 2007) or ASJ Model-1998 (Yamamoto, 2010). Since the latest CNOSSOS-EU (Kephalopoulos, Paviotti, & Anfosso-Lédée, 2012) framework has been developed and this methodology will become mandatory in the EU Member States, the comparison of different noise assessment methods or model interpretations (Kephalopoulos, Paviotti, Anfosso-Lédée, et al., 2014; Morley, Hoogh, Fecht, et al., 2015; Jónsson & Jacobsen, 2008) is becoming increasingly important for noise mapping software development.

Noise management is a systematic engineering. Some information technologies like Geographical Information Systems (GIS) (Kluijver & Stoter, 2000), Global Position System (GPS) and database are indispensable in traffic noise mapping, especially for integrating measurement data from mobile noise monitoring terminals in calculation (Manvell, Ballarin Marcos, Stapelfeldt, et al., 2004; Bennett, King, Curn, et al., 2010) or collecting accurate traffic information (Asensio, López, Pagán, et al., 2009). Maisonneuve, Stevens, Niessen, et al. (2009) proposed an interesting work which is to turn GPS-equipped mobile phones into noise sensors that enable citizens to measure their personal exposure to noise in their everyday environment. Thus, each mobile user can contribute by sharing their GPS information, and measurements to generate a noise map.

In order to produce accurate, fast, and cheap real noise maps, some Integration systems were developed to solve dynamic noise mapping problems, as SADMAM system (Manvell et al., 2004) and DYNAMAP project (Sevillano, Socoró, Alías, et al., 2016). Based on SADMAM, Perera and Páez (2006) proposed a system to update noise maps with integrating mobile and fixed noise monitoring terminals, GIS database, existing acoustic database and existing noise maps.

In the DYNAMAP Project, a mixed approach of noise maps, statistics and monitoring stations is used. One of the main objectives of DYNAMAP is to demonstrate that the automation process will lead to a significant reduction in the resources needed to update noise maps (time, costs and dedicated personnel). A lot of technologies and methodologies are developed to lower cost, such as a statistical road classification method used in stratified spatial sampling of road traffic noise (Zambon, Benocci, & Brambilla, 2016a) and a clustering method for urban roads to optimize their noise monitoring (Zambon, Benocci, & Brambilla, 2016b).

Most of the commercial noise mapping software can support parallel computing, like SoundPLAN or CadnaA, but they employ dated task scheduling and computing technology at the same time. Some powerful and mature technologies like intelligent optimization, cloud computing and heterogeneous computing are not yet widely used. Sometimes intelligent optimization methodologies are used in the prediction model development or environmental noise assessment. For example, Souza and Giunta (2011) proposed an Artificial Neural Networks (ANN) based method to model the influence of urban indices on the sound ambience of the streets. And Szwarc and Czyzewski (2011) introduced a railway noise prediction method based on GA. However, in the full life cycle of traffic noise mapping, a lot of aspects still requires further improvement, as data processing, task scheduling, computational efficiency, fast update calculation, etc.

This paper focuses on computing efficiency problems. Some classified methods of efficiency improvement in noise mapping are listed in Table 1, and the scope of our works in this paper is also shown in this table.

3. Calculation kernel developed for CPU and GPU

In this paper, we employed a heterogeneous computational environment combined with distributed computing and CPU-GPU cooperative computing. The mixed computational pattern can significantly improve the computational efficiency of noise mapping. For the accuracy of calculation results, not only traffic noise prediction model, but also its algorithm implementation should be remarkably consistent on GPU and CPU.

3.1. Prediction model

The prediction model in our calculation kernel follows the procedures outlined in the Technical Guidelines for Noise Impact Assessment (HJ2.4-2009, 2009), which was established by the Ministry of Environmental Protection of the People's Republic of China in 2009. In HJ2.4-2009, the source emission model and the propagation model are