

Automatic Quadrilateral Mesh Generation System Using Large Language Model

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The finite element method often uses quadrilateral meshes, which are better than triangular meshes for calculating results. However, it is still hard to automatically generate quadrilateral meshes. This study proposes a system that automatically generates meshes using large language models. We show that state-of-the-art large language models can successfully generate high-quality quadrilateral meshes for simple two-dimensional shapes. This suggests that there is potential for automated structural design workflows.

***Index Terms*— Large language model, electromagnetic analysis, finite element method, mesh generation.**

I. INTRODUCTION

SIMULATION-BASED structural design has gained attention in the manufacturing industry as a means to reduce the number of time-consuming and costly prototypes. The finite element method (FEM) has emerged as a key analytical tool, with applications across various fields from electromagnetic analysis to thermal analysis. While FEM calculations involve dividing structures into elements called meshes, quadrilateral (hexahedral) meshes are known to provide higher computational accuracy compared to triangular (tetrahedral) meshes. However, the automatic generation of high-quality quadrilateral meshes for complex structures remains a challenging problem, with current practices primarily relying on manual or semi-automatic mesh generation by engineers [1]. The objective of this research is to develop an automatic quadrilateral mesh generation algorithm utilizing large language models (LLMs), which have shown rapid advancement in recent years. This paper reports on the feasibility verification of an automatic mesh generation algorithm using LLM for simple two-dimensional shapes as the first step of our research.

II. AUTOMATIC QUADRILATERAL MESH GENERATION SYSTEM

This research proposes an automatic quadrilateral mesh generation system using LLMs to generate high quality quadrilateral meshes for arbitrary shapes. Fig. 1 shows an overview of the automatic mesh generation system. The system consists of two main processes: shape division and mesh generation. Specifically, the system performs appropriate shape division on a given two-dimensional shape and applies suitable mesh generation algorithms to each divided shape. This section explains the details of the automatic mesh generation system.

A. Shape Division

This process uses LLM to divide the computer-aided design (CAD) model to generate high quality meshes. The details are as follows.

1. User Instruction Input

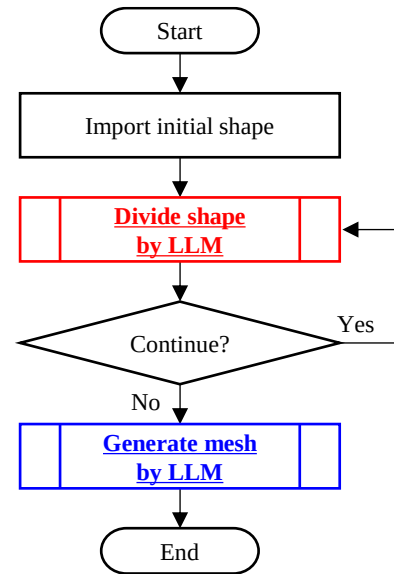


Fig. 1. Overview of automatic mesh generation system.

The system receives textual instructions from the user regarding shape division. The LLM will prioritize these user instructions when considering shape division strategies. User instructions can be left empty.

2. LLM's Division Method Decision

The LLM receives the generation program for the input shape, an image of the shape, and user instructions to determine the appropriate division method and the need for division itself. If division is deemed necessary, the LLM selects the appropriate division strategy: simplification or line symmetry.

3. LLM's Generation of Division Program

The LLM generates an appropriate division program based on the chosen shape division strategy. For simplification, the LLM selects two vertices and generates a program that divides the shape using a straight line connecting these vertices. For line symmetry, the program generates division lines using rule-based calculations of the shape's center of gravity and symmetry axis angle information.

4. Division Execution

The generated division program is applied to the CAD model to perform the actual division.

5. Evaluation

Once the division is completed for all surfaces, the user or LLM reviews the division results and decides whether to keep this division method and continue with further divisions.

B. Mesh Generation

This process performs appropriate mesh generation for the CAD model after the shape division is completed. The details are as follows.

1. User Instruction Collection

The system receives text instructions from the user regarding mesh generation. The LLM prioritizes these user instructions when considering mesh generation strategies. User instructions can be left empty.

2. LLM's Mesh Generation Method Decision

Based on the shape image and the user instructions, the LLM proposes the optimal mesh generation method from pave mesh, circle mesh, and mapped mesh.

3. Mesh Generation Program Creation

Based on the LLM's decision, the system implements a specific mesh generation program.

4. Mesh Generation

The generated mesh generation program is applied to the CAD model to generate the actual mesh.

5. Evaluation

Once mesh generation is completed for all surfaces, the user or the LLM reviews the final mesh generation results and decides whether to accept them. If accepted, the mesh generation process ends.

C. Experiment and Evaluation

This study evaluated the proposed automatic quadrilateral mesh generation system through multiple experiments with different shape types and LLM models. The experiments used two basic shapes for testing: keyhole and dumbbell shapes. The experimental process was designed to run with minimal human intervention to maintain consistency across experiments. For the shape division process, the user instructions were left blank, and for the mesh generation process, the general instruction "Generate a mesh with 1mm size for all surfaces." was given. To ensure practical completion times, we limited the maximum number of iterations to five. This research used Cubit 2023.11 for CAD and meshing.

Tables I and II show the results of mesh generation quality calculations for keyhole and dumbbell shapes, where the mesh quality metrics for each model are the average and standard deviation of five trials. Fig. 2 shows examples of mesh generation results for keyhole and dumbbell. From these results, it can be seen that state-of-the-art LLMs such as gemini-1.5-pro and gpt-4o can perform high-performance shape division and mesh generation for both shapes. In particular, gemini-1.5-pro was found to be able to generate stable meshes with a small

TABLE I
COMPARISON OF MESH QUALITY FOR KEYHOLE

Model	Aspect ratio [-]	Skew [-]	Taper [-]	Minimal angle [°]
gpt-4o-2024-11-20	1.25±0.21	0.13±0.04	0.08±0.01	78.8±2.8
gpt-4o-mini-2024-07-18	1.20±0.16	0.22±0.09	0.15±0.02	70.6±4.2
gemini-1.5-pro	1.07±0.00	0.09±0.00	0.10±0.00	80.3±0.0
gemini-1.5-flash	1.09±0.01	0.11±0.03	0.13±0.03	77.2±2.9
claude-3-5-sonnet-20241022	1.17±0.01	0.15±0.02	0.11±0.02	76.8±1.8

TABLE II
COMPARISON OF MESH QUALITY FOR DUMBBELL

Model	Aspect ratio [-]	Skew [-]	Taper [-]	Minimal angle [°]
gpt-4o-2024-11-20	1.18±0.02	0.13±0.01	0.09±0.01	78.9±0.6
gpt-4o-mini-2024-07-18	1.14±0.04	0.14±0.01	0.12±0.02	76.7±0.8
gemini-1.5-pro	1.10±0.05	0.11±0.01	0.11±0.01	78.9±0.2
gemini-1.5-flash	1.08±0.00	0.11±0.01	0.12±0.01	77.7±1.3
claude-3-5-sonnet-20241022	1.41±0.42	0.22±0.13	0.13±0.01	70.6±8.9

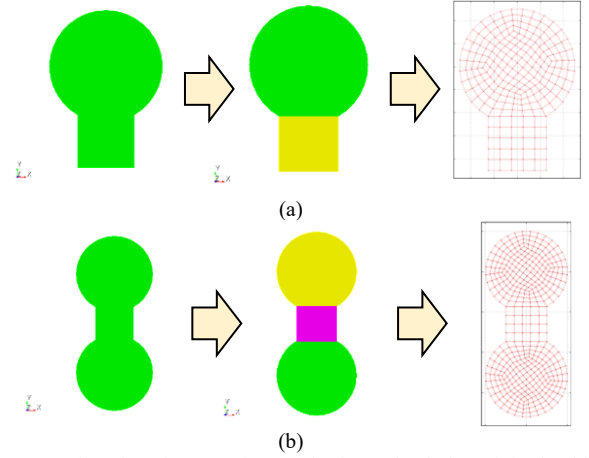


Fig. 2. Examples of mesh generation results for (a) keyhole and (b) dumbbell.

standard deviation over five trials. In addition, gemini-1.5-flash was found to be able to generate meshes that were not inferior to those for large-scale models, despite the small model size. On the other hand, claude-3-5-sonnet was found to have issues with its spatial perception ability.

III. CONCLUSION

The study proposed an automatic quadrilateral mesh generation system using LLMs. The results showed that state-of-the-art LLMs, especially gemini-1.5-pro, can generate high-quality meshes for simple two-dimensional shapes. Future work will focus on using this approach to complex industrial structures like coils and motors, as well as three-dimensional geometries.

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