A CHECK OF MESH QUALITY

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INTRODUCTION

The accuracy of finite element calculations is dependent upon the quality of the mesh. Degenerate elements with small volumes in conjunction with large displacements of the associated nodes may lead to large local errors of the solution. The worst scenario results in an insolvable system of equations.

Even if a mesh is valid and all of the elements are approximately the same size, the quality, as measured by parameters such as aspect ratio, skew, and Jacobian quality metrics, may be poor. Theoretically, the FE solution should approach the exact solution as the size of the largest element approaches zero. It has been demonstrated, however, that if dihedral angles approach $\pi$ as the element size decreases, convergence to the exact solution may fail. ABAQUS, for example, checks the distortion of each element through the angle between isoparametric lines of each element. In general, the criterion set for this test consists of verifying whether the angle is greater than 45º or less than 135º in order to reduce the influence of the element distortion on the accuracy of the numerical integration.

An assessment of mesh quality using ABAQUS, for example, is conducted during the pre-processing phase. In an effort to couple a check of mesh quality with our custom-written meshing software (IA-FEMesh), we have developed a stand alone application.

METHODS

A goal of the stand alone viewer is to make the mesh generation process more efficient by providing rapid, visual feedback to the user (Figure 1). Our mesh quality application (Figure 2) utilizes the open-source VERDICT library to analyze element quality according to several metrics that have been proposed in the literature (Knupp 2000, Knupp 2001, and Knupp 2003). In addition to readily identifying zero-volume elements, the user is allowed to choose between a number of mesh quality metrics: including volume, Jacobian, scaled Jacobian, edge-ratio, and the Frobenius aspect.

Figure 1. Contours illustrate the mesh quality on an element-by-element basis.

The Jacobian calculates the partial derivatives of the hexahedron shape functions with respect to the Cartesian coordinate system. The edge ratio provides the ratio of the longest to the shortest edge in each hexahedron. The Frobenius measures the average condition number of
the transformation matrix from an isosceles configuration for each of the 8 corner tetrahedra of a hexahedron. A scaled Jacobian is also available that scales the resulting Jacobian between +1 and -1. Quality values are assigned per element and visualized using the VTK library. The user can interact with the mesh and change the mesh quality metric in real-time using the VTK pipeline architecture.

Since datasets generally contain a large number of elements, interactive tools have been developed that allow users to isolate and examine both individual elements and element groupings. A user may dynamically position “cutting planes” within the dataset to expose the internal mesh. Furthermore, the elements may be scaled (shrink option) for improved visualization (Figure 1). The surface normals may also be displayed (Figure 2).

RESULTS AND DISCUSSION

Figures 1&2 illustrate the mesh quality tool applied to a phalanx bone of the hand. The most distorted elements (Jacobian metric) are highlighted in red (Figure 2). Elements of poor quality can quickly be identified, and if need be a new mesh generated, before importing the resulting mesh into a finite element package such as ABAQUS.

We assert the uniqueness of our work not in the development of specific mesh quality metrics. Instead, our contribution comes from providing a framework to couple these individual techniques together into a simple, timesaving stand-alone application.

Algorithmic extensions to the VERDICT mesh quality library are being developed to mirror the angle and edge length constraints imposed by FE solvers, such as ABAQUS.

SUMMARY/CONCLUSIONS

A mesh quality visualization tool has been developed to facilitate the generation of high quality finite element mesh definitions. The current tool was developed initially to support hexahedral meshes. The tool supports the ability to display a number of mesh quality metrics and to interact with the mesh to explore mesh quality before importing the mesh into a finite element package for analysis.

REFERENCES


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