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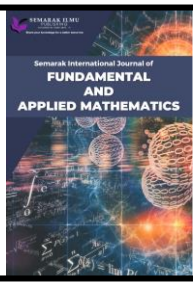

Volume and Surface Area of 3D Mesh Objects : A Matlab GUI

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ABSTRACT

In many applications of science and engineering, the real physical related objects are usually modelled in terms of mesh objects, where, the mesh will be used during computation or simulation. For most cases, a good mesh is required in order to increase the accuracy of the results. As the mesh represents the original object, the mesh should have similar physical properties of the original object such as the surface area or the volume. However, finding the value of these parameters could require extra computational cost and increase overall time taken to solve the problem. Thus, it might be useful if these parameters can be determined separately to ensure good mesh is used before any simulation is performed. In this study, a Matlab GUI is developed to enable user for easily computing the volume and the surface area of three-dimensional mesh objects. In order to use the GUI, user will firstly need to import the Mesh that is generated by the software Netgen Mesh generator. Once any mesh is imported as an input to the GUI, the program will use the concepts in vectors, which includes dot and cross products, to compute both parameters. Apart from presenting briefly the steps in creating the GUI with Matlab, this paper will also provide some examples to demonstrate the use of the GUI.

1. Introduction

Many problems in applied science and engineering involve geometric objects. Most of the time, the problems cannot be solved analytically and when numerical methods are implemented to solve the problems, mesh objects are used to approximated the related objects involved in the problem (see the previous studies by [1-5]). For example, in a study of heat transfer by [4], the domain involved, as a three-dimensional object, is firstly partitioned into small pieces of polyhedron before simulation is made using the partitioned object. In this case, the collection of the small pieces of polyhedron as one whole object is sometimes called as the mesh object. Similarly, during the study of electric fish in [5], an object is firstly approximated by an appropriate mesh before numerical

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integration is performed over the mesh in investigating how electric fish recognizes the object according to the polarization tensor of the object.

In order to partition objects into mesh, a few software such as Netgen (as documented in [6]) or Gmesh (as presented in [7]) can be used. In this case, it is important to use good meshes to ensure, for example, the accuracy of the numerical method implemented. Thus, investigating several properties of a particular mesh could be very useful to justify how good the mesh is. At the moment, there were only less methods available in academia to describe mesh objects. Such methods if available mostly were for specific problems or investigations and thus, could be difficult to understood as well as implemented in any other problems.

Thus, this paper presents a MATLAB graphical user interfaces (GUI) that provides two basic properties of mesh objects, which are the surface area and the volume. In order to use the GUI, the mesh objects must be firstly generated by Netgen. After that, a few information about the mesh can then be imported by the GUI, where, that information will be used to compute the surface area and the volume for the mesh object. The computation is based on the simple formulation in calculus and vectors that suit to many applications of science and engineering. Based on the outputs of the GUI, the mesh can be claimed to be a good approximation to original the object if the surface area or volume of the mesh are almost similar with the surface area or volume of the original object.

2. Methodology

In developing the GUI, the similar methods as presented in Ahmad Khairuddin *et al*. [8] are considered. These methods will be presented in Section 2.1 and Section 2.2. Moreover, in Section 2.3, the steps in developing the GUI using Matlab will be briefly explained.

2.1 Netgen

In order to use the GUI, a mesh for a specified object must be firstly chosen and generated by the software Netgen. Netgen is an open-source powerful software developed by Joachim Schberl at Johannes Kepler University Linz using C++ language and available for Unix, Linux and Windows. The software generates mesh for an input of a three-dimensional object by partitioning the object into a set of finite elements such as triangles or quadrilaterals for the surface, and tetrahedra or hexahedra for the volume.

For generating a mesh, a geometry in a .geo file will be firstly loaded to Netgen (a manual for NETGEN can be downloaded from [9]). This can be done by selecting the menu `File’ and then, choose `Load Geometry’. The package of the software includes .geo files for many ordinary geometries for finding their meshes. Figure 1 shows the display of Netgen after the sphere in sphere.geo is chosen as an example. The button ‘Generate Mesh’, as shown by the red arrow in Figure 1, can then be clicked to generate the mesh for the geometry.

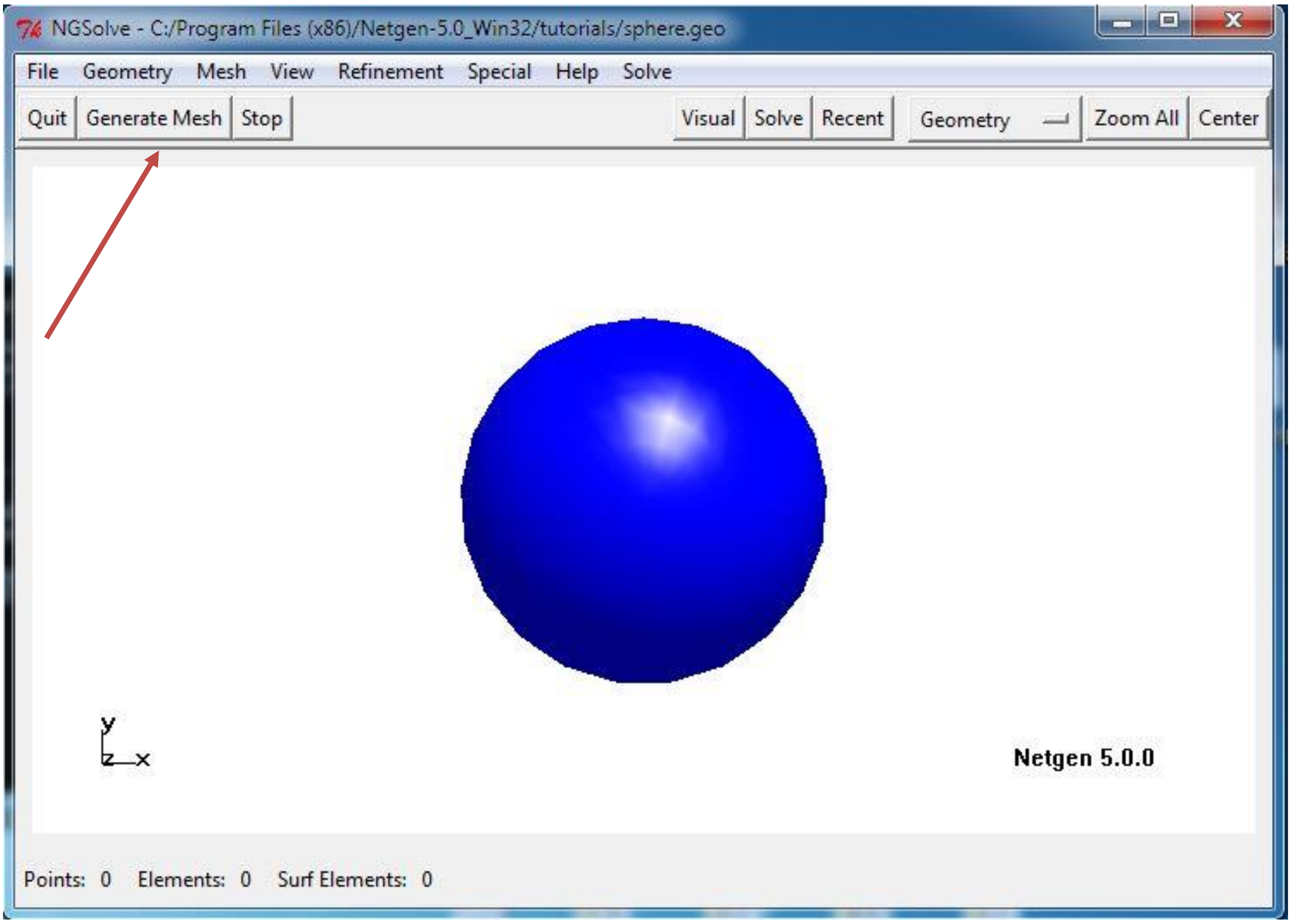

Fig. 1. The display of a sphere from the file sphere.geo in Netgen

Figure 2 next shows the mesh generated for sphere.geo by Netgen. Here, since the surface of the mesh is constructed by a finite number of triangles, the mesh is commonly called as triangular mesh. In addition, the process of generating triangular meshes for objects as triangularization. On the other hand, the volume of the mesh is built by a finite number of tetrahedra. The total triangles and tetrahedra are given by 'Surf Elements' and 'Elements' respectively in Netgen. Here, as shown in Figure 2, the mesh of sphere.geo consists of 620 triangles and 2100 tetrahedra.

The mesh of any object, generated by Netgen, can be saved in a .vol file. This can be done by selecting the menu 'File' and then, choose 'Save Mesh'. The mesh file contains three vertices for each triangle in the surface of the mesh, four vertices for each tetrahedron inside the mesh and also the coordinate of all vertices in 3D Cartesian coordinate system. Figure 3 shows a triangle on the surface of the mesh and also a tetrahedron inside the mesh. Based on the vertices of all triangles and tetrahedra, several properties of the mesh can be determined.

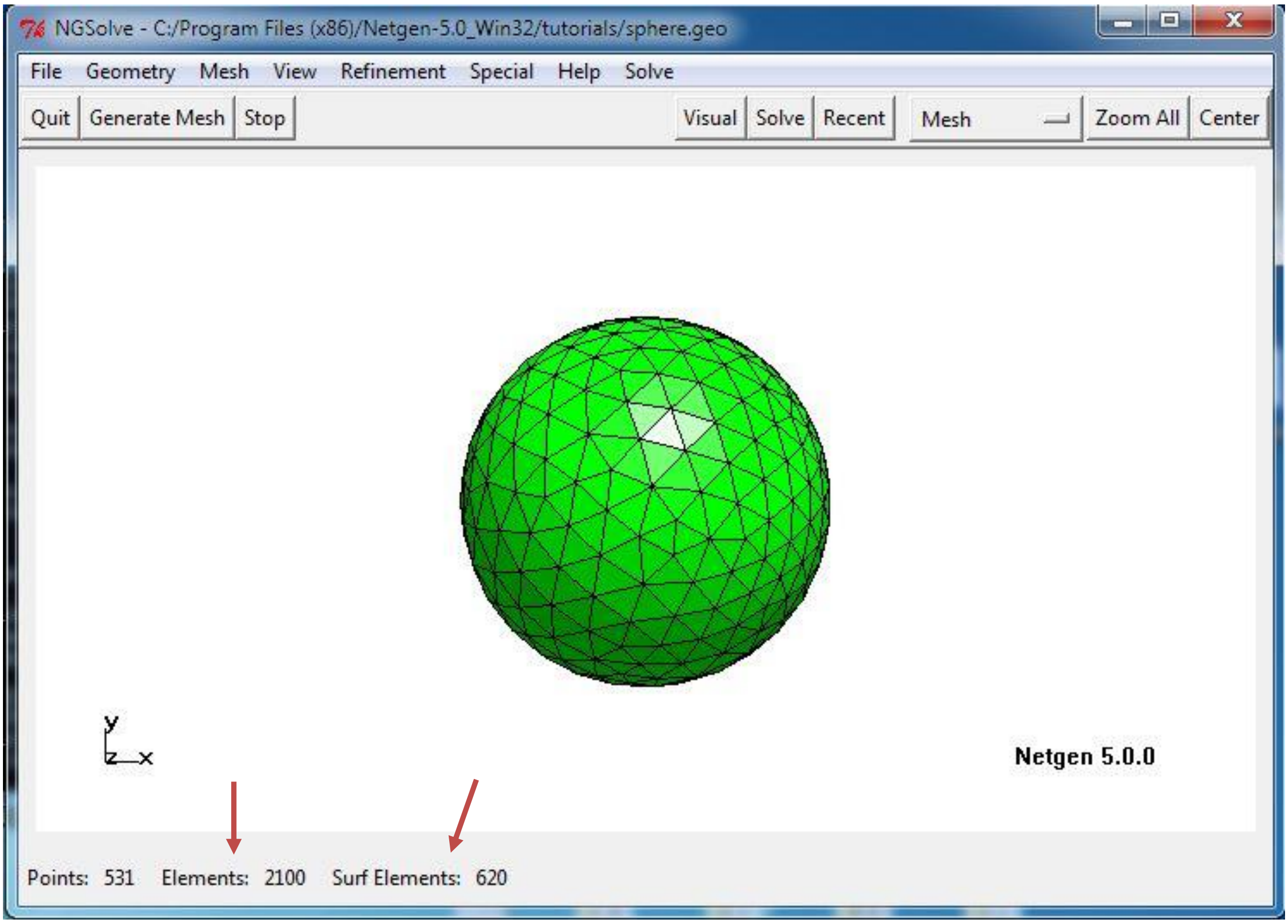

Fig. 2. The mesh of sphere.geo generated in Netgen with 620 triangles and 2100 tetrahedra

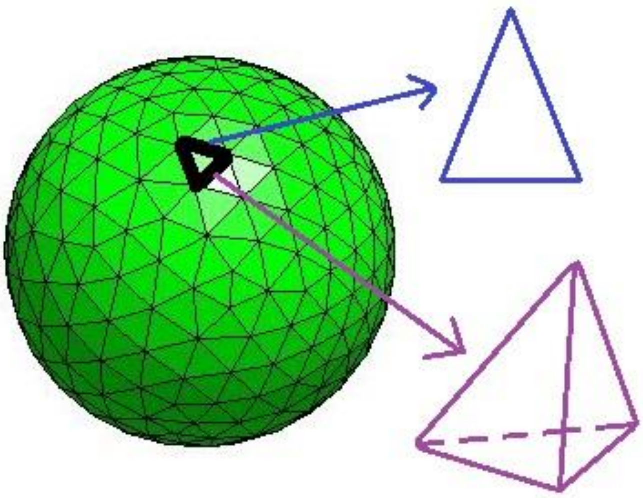

Fig. 3. A triangle on the surface and a tetrahedron inside a mesh

2.2 Computation of the Surface Area, Volume and Centroid of a Mesh

The surface area of the mesh object as a triangular mesh is simply given by the total area of all triangles on the surface while the volume of the mesh is given by the total volume of all tetrahedra inside the mesh. Given the coordinate of all vertices for each triangle, the area of each triangle can be computed by using the cross product between two vectors, where, those vectors are any two sides of the triangle. Similarly, given the coordinate of four vertices for each tetrahedron, the volume of each tetrahedron can be obtained by using both dot and cross products between vectors. These techniques have been used for computing surface area and volume of mesh objects in [8] and also can be found for example in [10], where, the techniques are usually taught in foundation courses to science and engineering students during higher level of education.

2.3 Programming in Matlab for Creating GUI

The GUI is created with two types of files in Matlab. The first file is the .fig of Matlab that stores all objects for the window interface of GUI. In this GUI, its window interface is created using the tool GUIDE in Matlab 2021. GUIDE allows object-oriented programming without writing any code, where, user can simply create an object with built-in function by simply clicking available options when running GUIDE. Figure 4 shows the default window interface in Matlab after GUIDE is run (by typing guide in the command window of Matlab).

In Figure 4, items in the red box on the left-hand side are a few available options for creating objects for a desired window interface. For this GUI, the following options are used to create objects for the window interface (the options are labelled by the red numbers in the small blue boxes in Figure 4).

1. A rectangular push button that can execute a specified function.
2. A static box for displaying texts or numbers with the following specifications.
    a. A static box for displaying texts and numbers when using the GUI.
    b. A static box for displaying label in the designed window interface of the GUI.
3. A static box for displaying a two or three dimensional graph.
4. A static box for grouping a few other static boxes.

Matlab will automatically generate a .m file when a .fig file is created. While the .fig file saves the layout and some functions for the window interface of the GUI, the .m is a Matlab function for executing the GUI with any functions defined in it. In this case, functions for computing the surface area and the volume of a mesh object will be defined in the .m file.

3. A Brief Description about the GUI

In this study, the GUI developed is called as Mesh Objects Info and the .m and .fig files for the GUI are named as MOinfo.m and MOinfo.fig respectively. Figure 5 shows the windows of the GUI after MOinfo is run in the command window of Matlab. In this window, it can be seen the name Mesh Objects Info appears at the top left of the window.

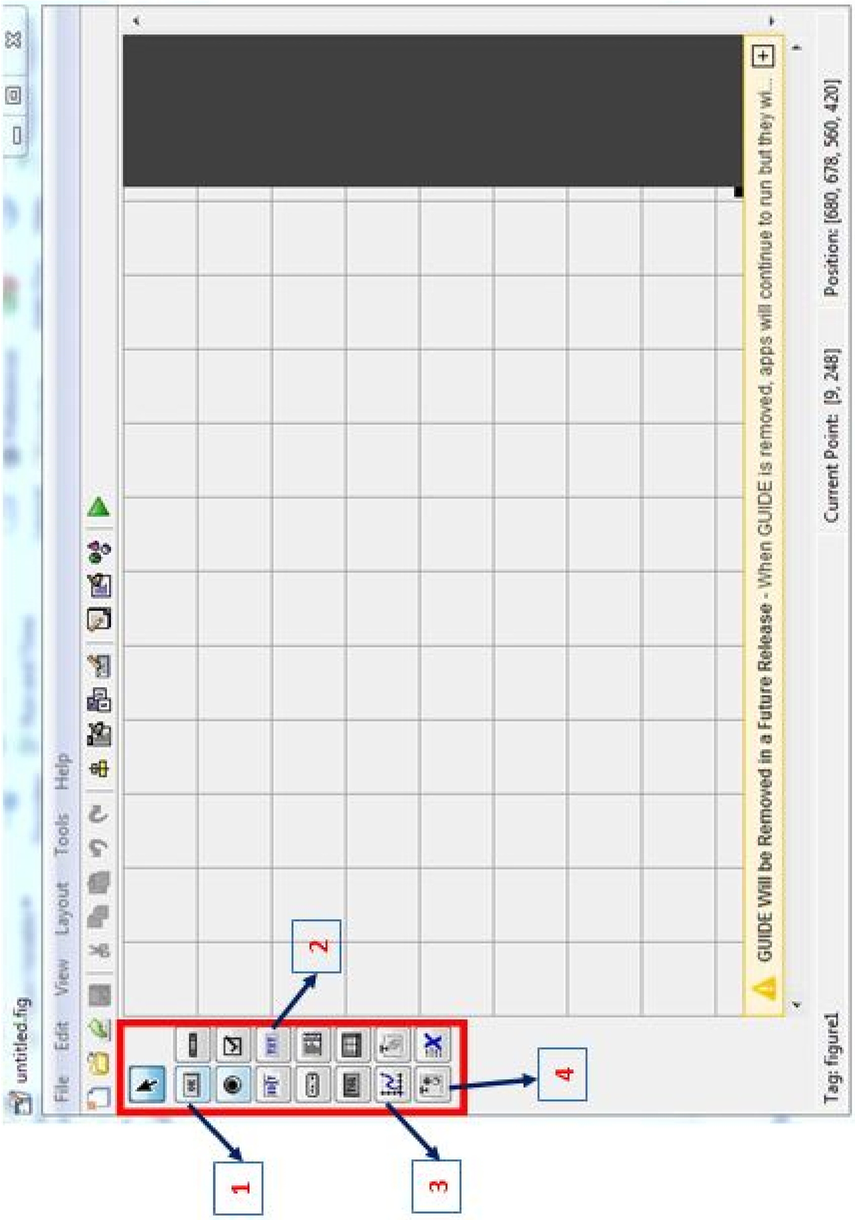

Fig. 4. Window interface after GUIDE is run with Matlab

Besides, in this window as given by Figure 5, there is a push button labeled Browse, created in MOinfo.fig with the first option when using GUIDE. In addition, there are four static boxes that display text (created with option 2 (b)), two static boxes that display numbers when using the GUI (created with option 2 (a)) and one static box (created with option 4) that groups four other static boxes. Besides, the box for displaying the mesh objects in the three dimensional coordinate system has also been created with option 3, where, by default, the box will show an empty two dimensional coordinate system when the GUI is firstly launched. Table 1 summarizes all objects created using GUIDE with the corresponding options. In this case, each object is labeled in Figure 5.

In addition, the remaining codes of a few mathematical functions for using the GUI are written in MOinfo.m. The first function is assigned to the push button A for locating and choosing the .vol file of a mesh object, generated by Netgen. From the .vol file, a code is also written to ask Matlab to import the coordinate of all vertices that create every triangle and tetrahedra for the mesh object.

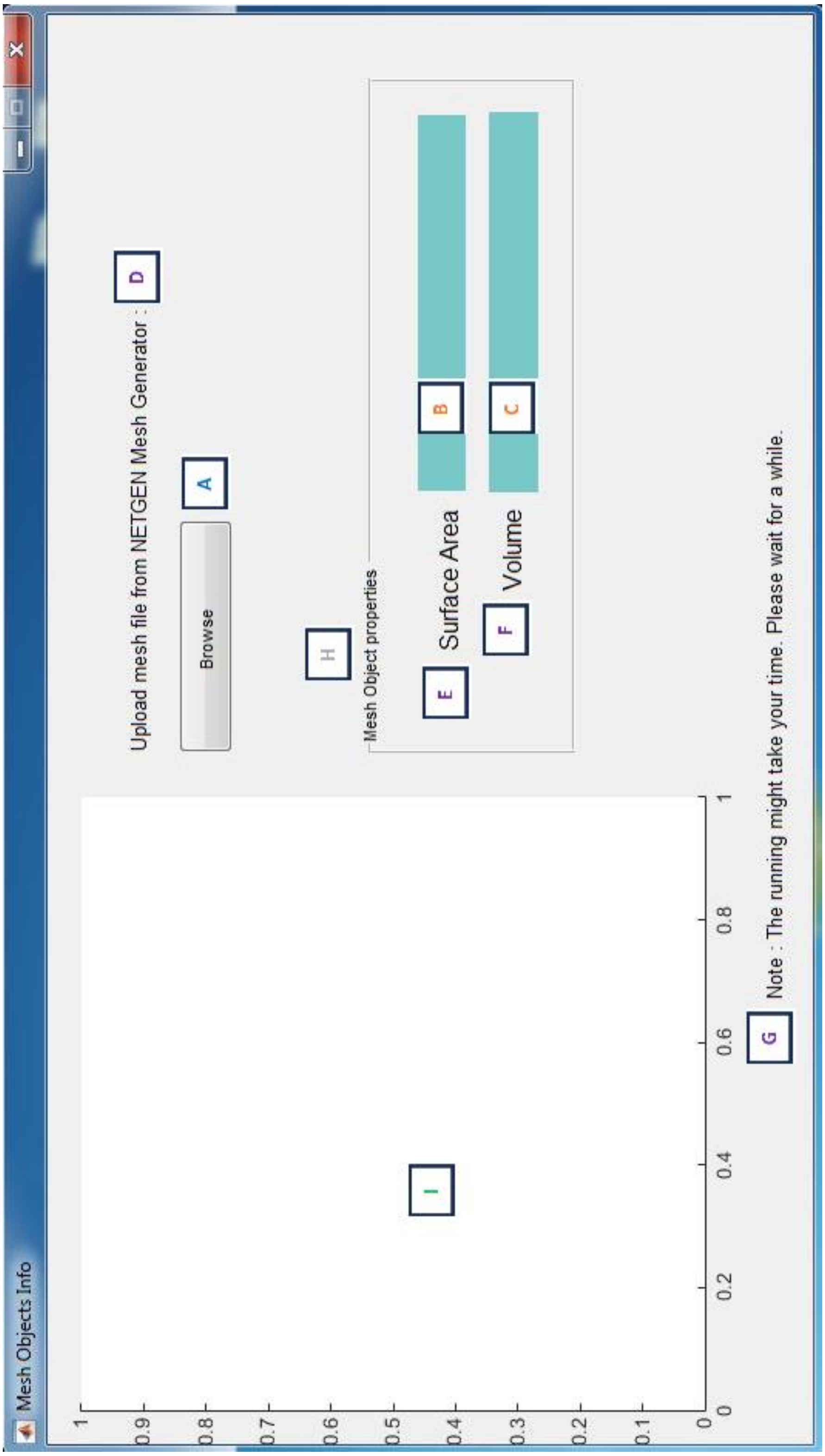

Fig. 5. The window after the GUI Mesh Objects Info is run with Matlab. The label A until I represent all objects created with GUIDE. See Table 1 to refer which option is used to create each object.

Table 1
All objects created for the GUI, as labeled in Figure 5, with the options used for creating them with GUIDE (see Section 2.3 and Figure 4)

Options (Color)	Objects
1 (Blue)	A
2a (Orange)	B and C
2b (Purple)	D, E, F and G
3 (Grey)	H
4 (Green)	I

Using the vertices, Matlab is then instructed to plot the mesh object with a specified code in MOinfo.m and the 3D graph of the mesh object will be displayed in the window by object I. Finally, based on the same vertices, another code is created to ask Matlab to compute the surface area and the volume of the mesh object, using methods in vectors. The values obtained for the surface area and the volume and centroid will be respectively displayed by object B and C in the window.

4. Examples

Figure 6, Figure 7 and Figure 8 show the display of the window for the GUI when the meshes used represent a sphere, a cube and a cylinder. For cube in Figure 7, the size of each side is equal to 1 and the surface area and the volume are accurately given by 6 and 1 respectively. This is because each surface of the cube is well partitioned into small triangles while the volume of the cube is well partitioned into small tetrahedra.

Besides, the surface area and the volume shown in Figure 6 approximate the volume of a sphere with radius 1. On the other hand, mesh object representing a cylinder of radius 0.5 and height 2 is used in Figure 8. Here, the actual surface area and the volume for the sphere of radius 1 each is respectively $4\pi \approx 12.57$ and $4\pi/3 \approx 4.19$. Meanwhile, the actual surface area and the volume for the cylinder of radius 0.5 and height 2 each is respectively $4(0.5)\pi + 2(0.5)^2\pi \approx 7.85$ and $2(0.5)^2\pi \approx 1.57$. The slight differences between the actual volume/surface area with the computed volume/surface area are contributed by the size of the mesh (the number of the triangles and tetrahedra used), where, better approximations could be obtained if finer mesh with larger number of triangles and tetrahedra is used to represent both objects.

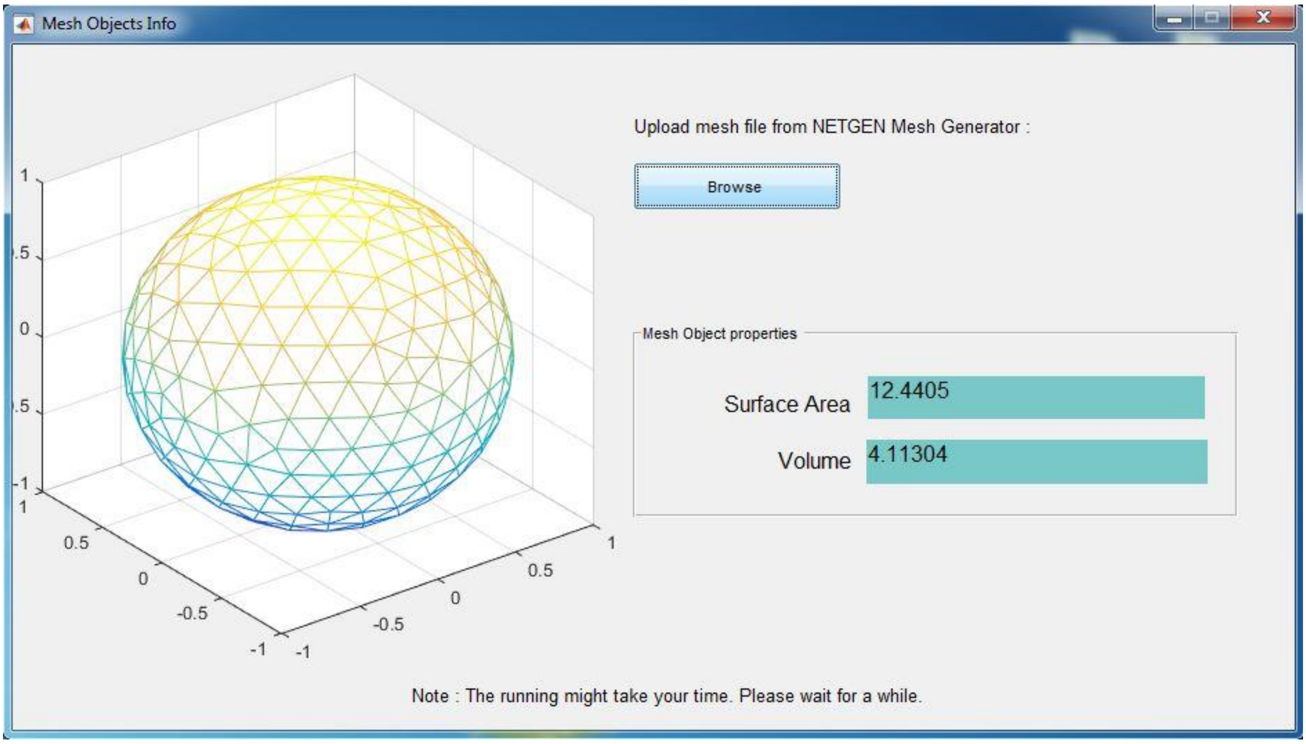

Fig. 6. The results when the mesh object represents a sphere

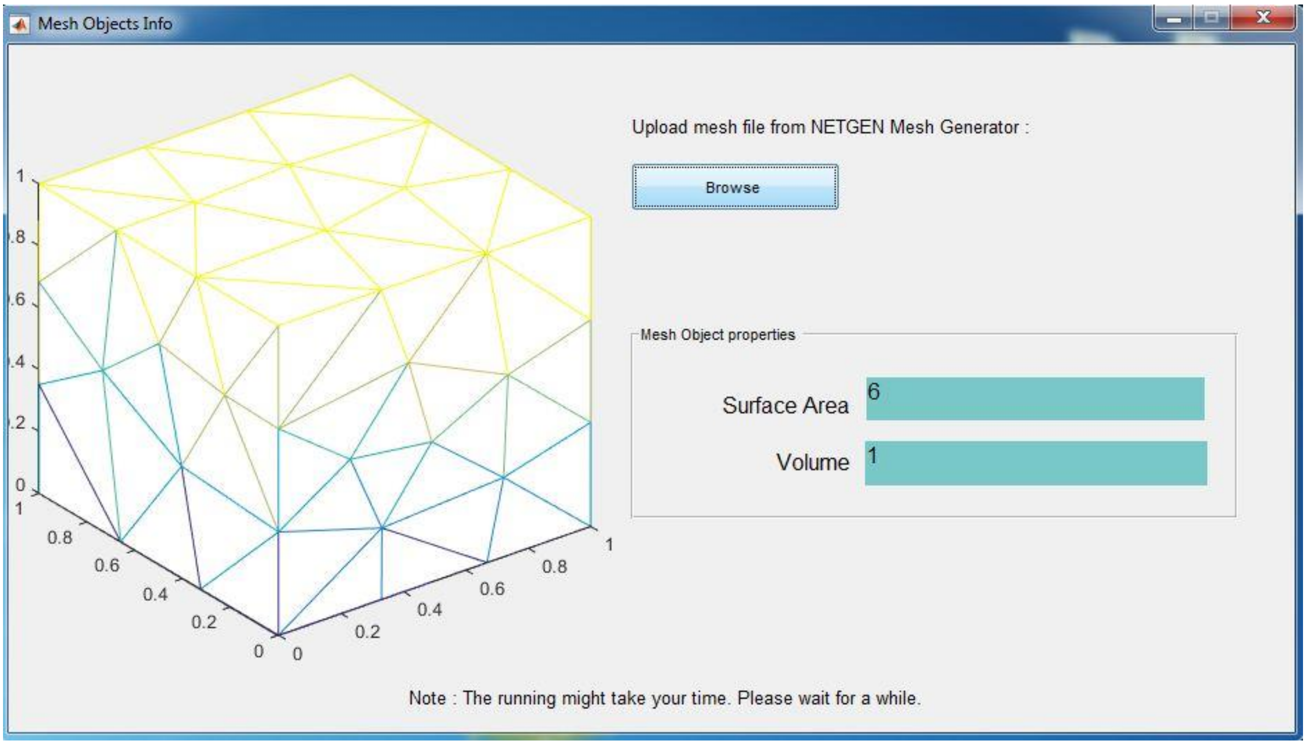

Fig. 7. The results when the mesh object represents a cube

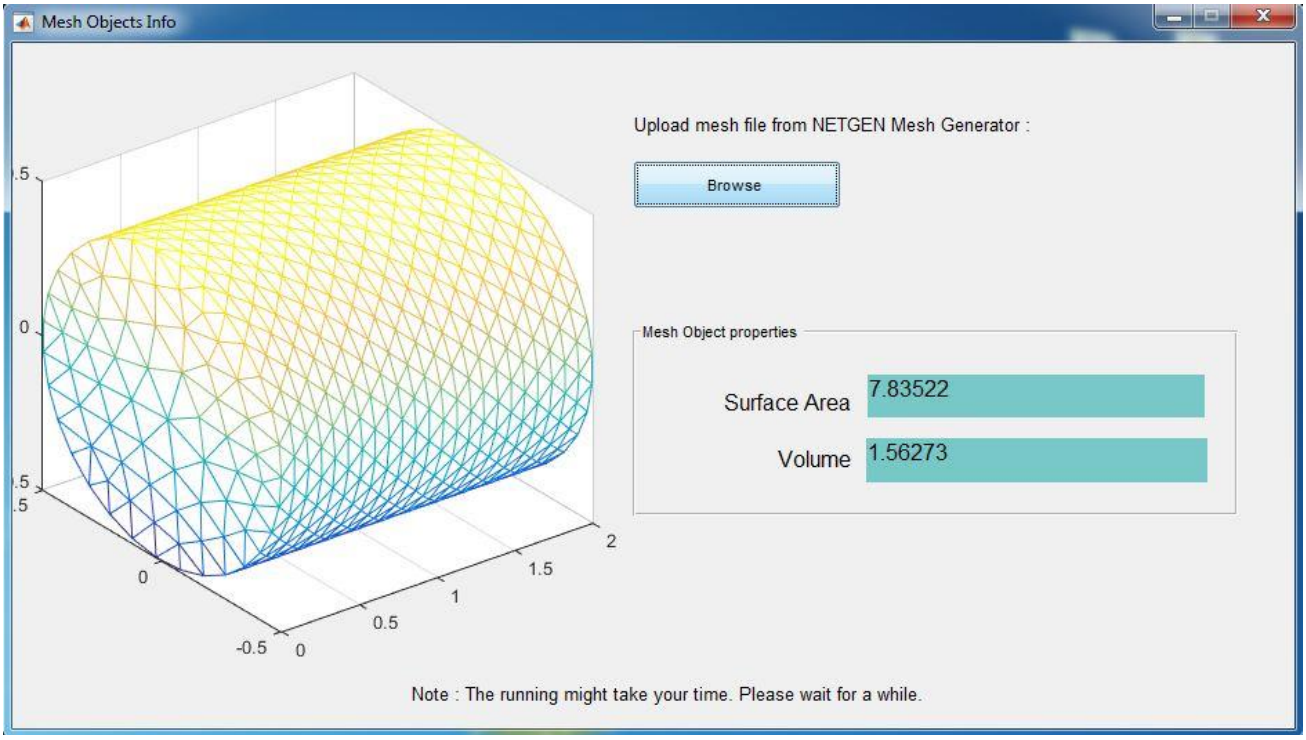

Fig. 8. The results when the mesh object represents a cylinder

5. Discussion, Conclusion and Future Works

In this study, a Matlab GUI has been developed, where, it produces several properties of a mesh representing a specified geometry after the mesh is imported in Matlab. It can be potentially applied during some investigations involving geometries in education, research or industry. However, the related mesh to be used with the GUI must be generated only by the software Netgen.

The GUI integrates a few disciplines of mathematics and physics such as calculus, geometries and vectors. This GUI could be very useful to students in their education on applying these topics. It can be introduced to science or engineering students during their foundation or in the first year of their degrees in highlighting the importance of mathematics in their study.

For educators, the GUI can be used as an example of adapting theoretical mathematics and physics in computer for solving the related problems. The GUI can also be applied by educators in any instiution of higher education as a supporting tool in their teaching of mathematic, science or engineering courses. Besides, the GUI could support researchers while performing simulation involving geometries and meshes, for examples in describing complex mechanical systems or investigating electrical properties of conducting objects.

Moreover, the GUI can support existing instruments in performing numerical modelling and simulation of mechanical systems for examples in automative or aeronautic engineering. Besides, it can also improve the existing applications based on electricity or electromagnetic such as the Electrical Impedance Tomography (EIT), given for example by [11], or metal detectors (see the previous studies by [12-14]. The GUI could also be a tool to geophysicists in exploring objects inside the earth, like the studies by [15-16], and help archaeologists to reconstruct images of broken historical monument (see [17]).

Finally, the GUI might be implemented to engineering based companies to improve their products. For instance, since the GUI can be integrated to existing software such as for medical or geophysical imaging, it can then be commercialized to industries of software engineering. The GUI could also be promoted to academic publisher as a supporting tool to textbooks in engineering or physical science.

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