

# **Maximum visibility building direction for layered manufacturing of jewel rings**

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## **Abstract**

Rapid prototyping is used in jewelry production since the introduction of Stereolithography Apparatus into the market. However, the building orientation is mainly decided by the experience of the operator rather than by any systematic analysis. A theory is therefore needed to analyze the best orientation of jewelry in rapid jewelry production. In this paper, a new orientation methodology is applied to jewel ring models to properly orient them for layer manufacturing. Jewel ring model built is then demonstrated to have better quality and less error. A case study is presented to illustrate the theory.

## **Introduction**

There are a number of researches being done in the past about part orientation in rapid prototyping or layered manufacturing. In 1994, Dietmar and Georges [1] proposed an expert system tool for determining the preferred part building orientation for stereolithography processes. An expert system was used to interact with the user to assess the most critical issues for deciding the optimal part building position. Three aspects were concerned in the expert system: surface finish, build time and support structure. Surface finish is considered as the most important, then the build time and finally, the support structures. The research defines specific geometric features such as a hole or a plane. Characteristic feature axis is defined and orientation of specific geometric features is described. In 1994, Allen, Dutta and Arbor [2] determined the best direction to build an object by layered manufacturing processes. The object was constructed with minimal support structures and was stable, and rested on a planar base. Ray-structure computation was used for each orientation in analyzing the support structure. The object intersects with rays will produce intersection points. The intersection points are then classified by the direction of normals. For face with normal pointing upwards, the corresponding point on the object does not need support, otherwise, the boundary points on the object may need support. For the latter, they will be further classified as supported or unsupported. If the angle between the face normal and the negative z-axis (building direction) is smaller than the user specified angle, support will be added. Otherwise, the points are unsupported. In 1995, Cheng, Fuh, Nee, Wong, Loh and Miyazawa [3] developed a multiple objective-function as a formulation to derive the optimal orientation for stereolithography process. Two objective functions are defined. The primary objective function considers the part accuracy. The influence by the types of surfaces on the accuracy will be represented by a weighting. The secondary objective function deals with the build time. The build time of the orientation obtained from primary objective function is checked. In 1997, Ng and Tan [4] optimized the part orientation in rapid prototyping processes by using feature-based functions. Three factors were used to

determine the optimal orientations: part accuracy, build time and support structures. Two functions: feature weight and feature objective value were used to analyze the part accuracy and to determine the potential candidates for optimal part orientation. Optimal orientation was then chosen from the potential candidates based on minimal building time using minimum number of layers. In 1997, Xu, Wong, Loh, Fuh and Miyazawa T. [5] sliced a CAD model directly by introducing an adaptive variable thickness slicer implemented on a solid CAD modeller and obtain an optimal building orientation by considering building time, part accuracy and part stability in SLA systems. The building time is measured in terms of the number of layers to be built. In building parts using SLA, part accuracy can be improved by minimizing the overhang area. Overhang area is calculated by using a function. If the projection of the mass center falls within the convex hull of the base geometry, the part is assumed to be in a stable building direction. If not, the part is unstable in that building direction.

In general, the previous researches concern mainly with part accuracy, build time, support structure and part stability of the prototype to be built in the RP machine. However in jewelry production, aesthetic quality is the main concern. In layer manufacturing of jewelry, the building orientation will definitely affect the quality of the prototype. Thus, a new methodology is introduced in this paper to give the best-built orientation for jewelry production.

### **Maximum Visibility Building Orientation**

Inherently, layered manufacturing is an approximation process even though direct slicing and adaptive slicing is used. As an aesthetic product (rather than a functional product), the staircase approximation error is better minimized from the observer. In layer manufacturing of jewelry, the best build orientation is the direction with least error visible instead of build time, accuracy, or minimization of support. In this paper, a new methodology, **maximum visibility building orientation** is introduced to find the best orientation of jewel ring in layer manufacturing.

For any three-dimensional object, different viewing direction will give different boundary information to the viewer. Except for highly symmetric objects, some viewing directions will provide the maximum information. The maximum visibility direction of an object is the direction in which maximum visible surfaces can be observed. In other words, it is the one giving the maximum projection area.

To obtain maximum visibility building orientation, two steps are needed. First, the orientation information is extracted from the CAD model. Second, the maximum visibility direction is determined using the projection area criterion. For step one, Gaussian image is used to represent the orientation information of the CAD model. For the second step, the Gaussian image is extended to include the local area associated with a particular viewing direction. Figure 1 shows the flowchart of the whole process.

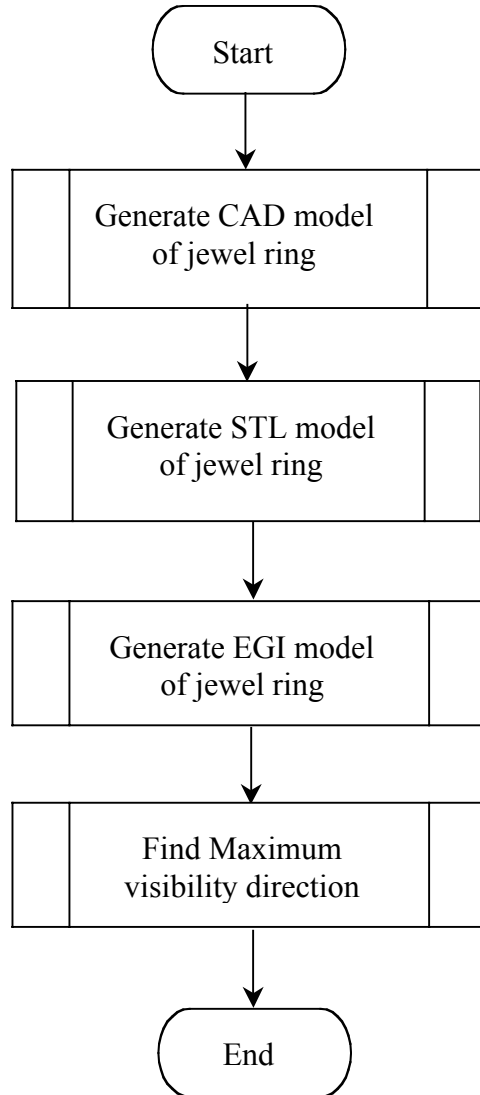


Figure 1. Complete process of maximum visibility orientation.

A CAD model of a jewel ring is first constructed. Then the STL file of the jewel ring is created to obtain approximated model with triangular facets. Next, the extended Gaussian image (EGI) model of the jewel ring is generated.

The Gaussian image of an object is obtained by associating with each point on its boundary surface a point on the Gaussian sphere which has the same surface orientation as shown in Figure 2. For convex object with positive Gaussian curvature everywhere, no two points have the same surface normal. Thus, the mapping from the object to the Gaussian sphere is invertible. However, if the convex surface has patches with zero Gaussian curvature, curves or even areas on it may correspond to a single point on the Gaussian sphere [6]. The many-to-one mapping encapsulates only the orientation information of the object. Other geometric information, like size, surface type, is not considered.

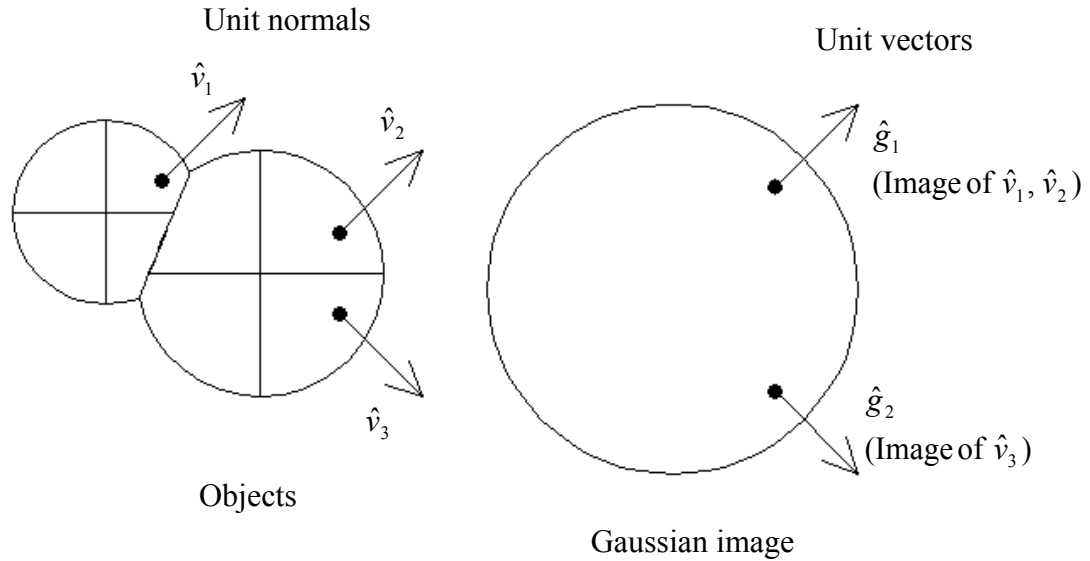


Figure 2. Gaussian image of an object.

The Gaussian image will only give a collection of directions. In other words, all elements have unit length. To extend the Gaussian image to rapid jewellery production, regions of the jewellery product visible in the same direction will be quantified as area. The EGI for rapid jewellery production use will thus have elements of Gaussian image weighted by area. In other words, elements in EGI may have different lengths. If a lot of boundary points in the object have the same outward normal, the corresponding image in EGI will be longer. The EGI of an object is independent of the position of surfaces and it represents the distribution of the surface normals. In general, it is difficult if not computationally expensive to find the EGI of non-convex object. A polygonal approximation is therefore used. In particular, triangular faceted approximation in STL file format is employed to obtain the EGI. Figures 3a – c shows an example of using EGI to represent an ellipsoid. Each arrow in Figure 3a represents a surface normal direction. The length of each arrow in the Gaussian sphere represents the area of facets with the same direction in Figure 3b. The tails of each arrow in Figure 3c are pointed from the center of the sphere.

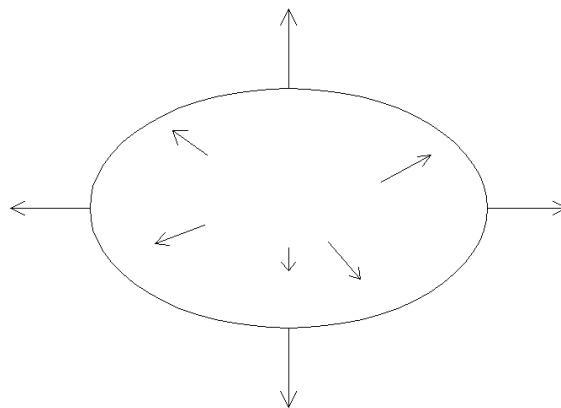


Figure 3a. Ellipsoid with its surface normals.

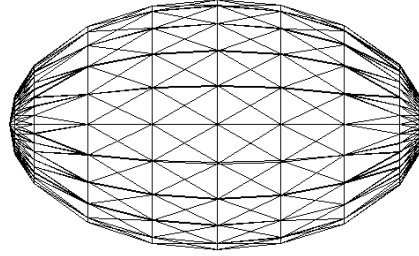


Figure 3b. Facet approximated model of the ellipsoid.

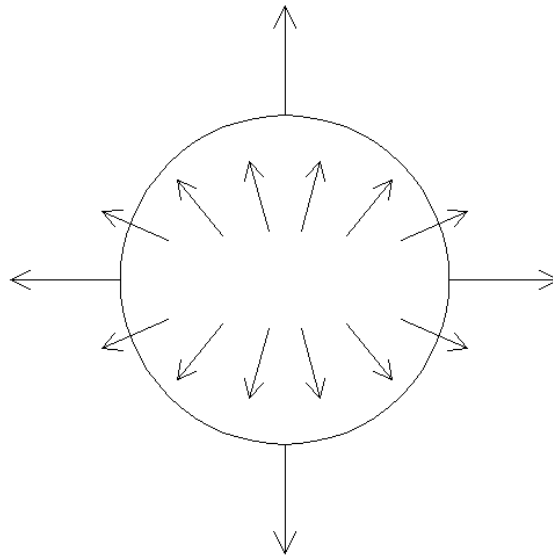


Figure 3c. EGI model of the ellipsoid.

For any object, there exists a direction in which maximal surfaces are visible. If the object is built by aligning maximum visibility direction with the building direction, the rapid prototype of jewel ring model will have the best quality.

Using the EGI model, the maximum visibility direction for a jewel ring model can be easily found. Each element in the EGI model has direction  $\hat{n}_i$  and magnitude  $\Sigma A_i$ .

The maximum visibility direction is the resultant vector  $\sum_{i=1}^m A_i \hat{n}_i$ .

However, a jewel ring has a through hole. If all the vectors  $A_i \hat{n}_i$  are summed, the resultant vector  $\sum_{i=1}^m A_i \hat{n}_i$  will be equal to zero. Thus, the component of all unit normals  $\hat{n}_i \cdot \hat{i}$ ,  $\hat{n}_i \cdot \hat{j}$  and  $\hat{n}_i \cdot \hat{k}$  will take the absolute value before the summation.

### Case study

A jewel ring model in Figure 4 is used for illustration. Figure 5 shows the facet model of jewel ring. Figure 6 is the EGI model. Figure 7 shows the maximum visibility direction obtained.

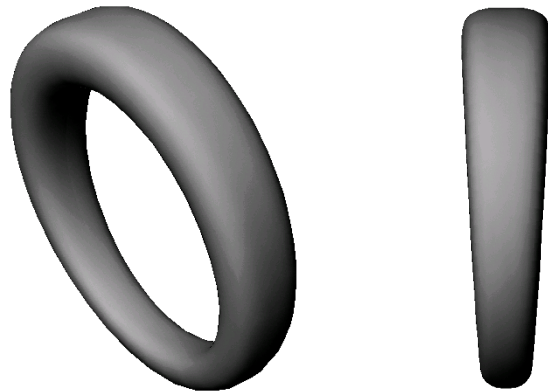


Figure 4. A simple jewel ring in isometric view and side view.

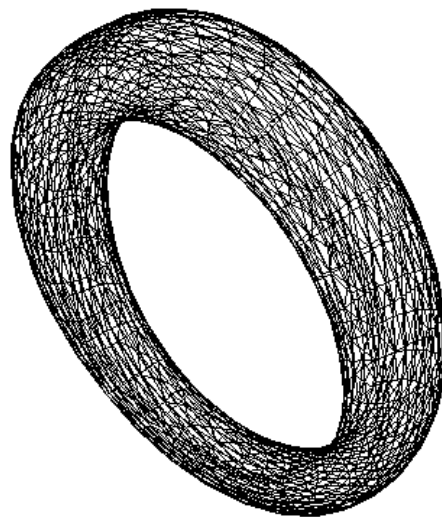


Figure 5. Facet model of jewel ring.

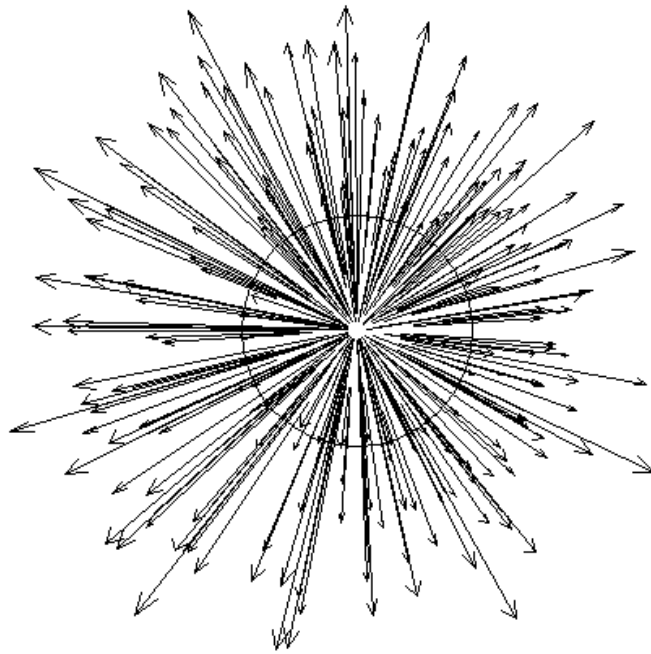


Figure 6. EGI of the jewel ring.

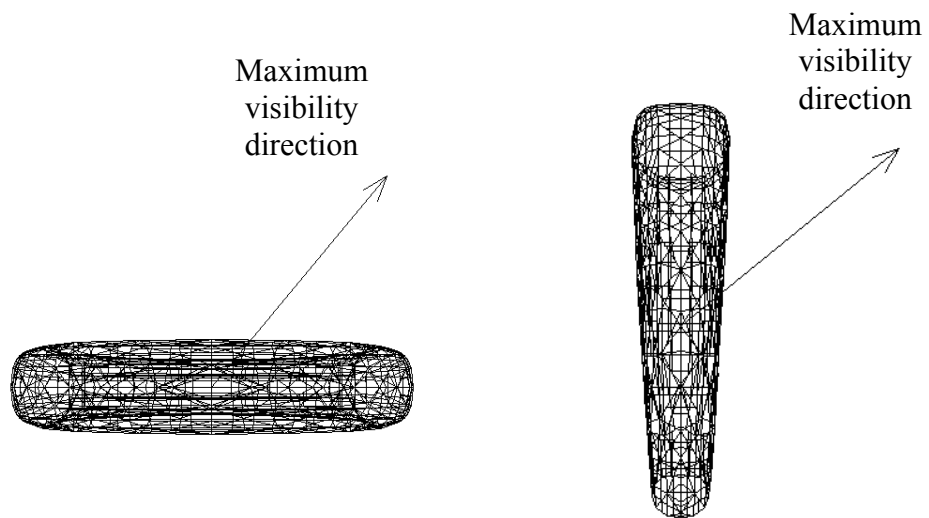


Figure 7. Maximum visibility direction in front view and side view.

## **Conclusion**

In this paper, EGI is used for determining the maximum visibility direction of the jewel ring model. However, EGI of STL model is used instead of EGI of smooth surface model or EGI of polygonal approximated model. If EGI of smooth surface model is used, an infinite number of normal needs to be computed. Alternatively, sampling may be needed for choosing characteristic points. If EGI of polygonal approximated model is used instead of EGI of faceted model, the data storage and computational time will increase as there are three vertices in a STL file facet but more than three vertices in a polygon.

In the case study, the maximum visibility building orientation is applied. If there is no systematic methodology for proper orienting the jewel ring model, the model will be built vertically (Figure 7) by experienced operator and the resulting quality may not be the best. Jewel ring model built has largest visible area. In fact, the method has potential to be applied to industry other than jewellery. This can be studied further in the future.

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## **References**

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