Title:
Primitive Detection from a Single View Image of an Engineering Model

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Introduction:

3D content-based image retrieval (CBIR) has gained paramount importance in the recent years widely due to its applicability in diverse fields from engineering to medicine. A key step in a CBIR system is to determine the features for all the objects in the database and for the query object. Typical features include color, texture, geometric primitives etc. A geometric primitive is defined as a curve or surface that can be characterized by an algebraic equation with a number of parameters [11]. Examples of primitives typically used in creating a 3D model are spheres, prismatic boxes, cylinders, cones etc (examples for 2D primitives include lines, circles, ellipses etc.). By performing basic boolean operations on these primitives, complex engineering objects can be constructed [10]. In the context of engineering objects, it is then apt to consider the primitives and their geometrical and topological characteristics as the high level content. It is to be noted that, with the advent of NURBS, solid models can be formed out of such representation as well, which are not considered in this paper.

Existing approaches of primitive detection can be classified into one of the following categories:

- Detection of 2D primitives from 2D data
- Detection of 3D primitives from 3D data
- Detection of 3D primitives from a single image

Amongst the three methods mentioned above, the detection of 3D primitives from a single image provides the maximum benefit as images are easy to obtain when compared to range data and 3D primitives give the maximum information. However, several problems associated with single view include difficulty in inverting projection, occluded features, low illumination conditions, incorrect camera placement, etc [1].

For the detection of 2D primitives like circles, ellipses, quadrilaterals [9] and [5] use Genetic Algorithms. By pruning the parameter space and the image space recursively, [2] discovers primitives. As the number of parameters of the primitive as well as the image features increase, the complexity increases.

In [3], metric reconstruction and texture acquisition from a single un-calibrated view of a surface of revolution (SOR) have been looked at. Polyhedral objects have been detected using segmentation and reconstruction in [7]. In [4], aspect hierarchies are used to infer 3D primitives from a single 2D image. In the lowest level of the aspect hierarchy boundary groups are placed, which map to faces, and the faces then map to aspects. The 3D primitives and their interrelationships are inferred from the aspects. Central to this approach is the implementation of a computationally complex conditional probability table which is generated by rotating each of the 10 primitives about its internal x, y and z axes at 10 degree intervals. A similar grammar-based approach for 3D inference from a single image is studied in [8]. In [12], real images are used as input and analysis is performed on a part level and an object level. The joints between parts of an object are studied and these results are also used in the 3D inference step of the algorithm. Objects which cannot be modelled as generalized cylinders cannot be used as an input to this method.

Other related works involve the use of range image data (i.e. three-dimensional data) that require sophisticated data acquisition system [6]. Broadly, primitives such as cone, torus, plane, cylinder and sphere are detected.

In this paper, we detect the 3D primitives from a single 2D image of an Engineering (CAD) model (instead of many 2D images of the 3D object). For example, given an image representing an engineering object, as in Fig.1 (a), our problem is to detect the 3D primitives that constitute the model. In Fig.1 (a), the primitives could be part of a cylinder (green contour) or a cone (yellow contour) as shown in Fig.1 (b). Moreover, a unified approach for detection of both SOR and prismatic primitives has been proposed. Apart from detecting typical primitives such as cylinder, this approach can also detect primitives such as prismatic cone etc. The demonstration of the algorithm is done on several thumbnail images of CAD objects. The effects of changing the viewing angle, illumination direction, and camera position are studied using the images of real world objects. It is also to be noted that this paper makes no attempt to solve the generic problem of an image representation of a CAD (Engineering) model. The following are the major contributions of the paper:

- A simple histogram-based approach has been employed
- Face fusion scheme has been proposed to detect 3D geometric primitives
- Several primitives are detected in a single run of the algorithm
- Since this is a non-parametric approach, it offers flexibility even when there are more than one set of parameters best describing the part.

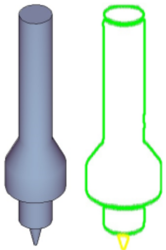

Fig. 1: (a) Test image, (b) primitive detection.

Main Idea:

Fig. 2 indicates the approach used in the paper for detecting primitives. Closed contours that bound a region of the image of the object are termed as faces. They are segmented one by one from the image of the object. The points constituting each contour are ordered in the anti-clockwise direction by sorting in ascending order the angles created by the line joining the centroid and every point and the X-axis. The slopes of the lines joining consecutive points on the contour are computed and a histogram is generated out of this analysis. The first and the second most frequently occurring slopes are selected and the points corresponding to these are counted and divided by the total number of points on the face. If this ratio is high then the contour is mostly made up of straight lines and corresponds to a primitive face image which is made up of straight lines (side faces of cylinder, cone etc.). The depth information is obtained by performing a Shape from Shading (SfS) for every contour. Using the depth, each contour can be classified as either prismatic or solid of revolution. The distance of every point on the contour from the centroid (hence forth known as centroidal distance) is used to differentiate between the elliptical and circular profiles of the contours. To summarize, using the centroidal distance, depth information and the ratio indicating the presence of straight lines, each contour is assigned a primitive type, termed as primitive face. The results are further refined by analysing the topological connectivity between the primitive faces. The primitives handled in this paper are box, cylinder, cone - surface of revolution (denoted as cone, SOR), cone - pyramid (denoted as cone,Pyramid), ellipsoid (object of revolution), elliptical prismatic, and spherical (both object of revolution and prismatic).

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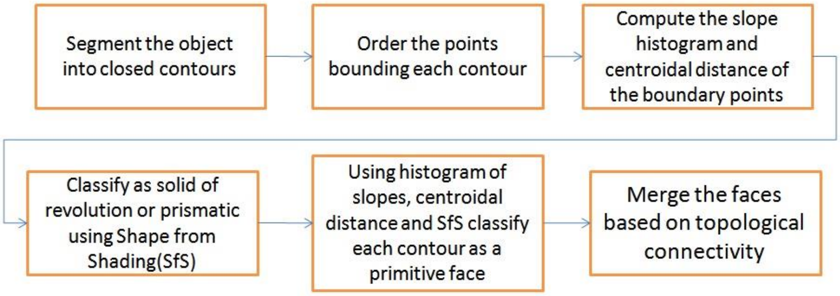

Fig. 2: Overview of the approach to detect primitives.

Conclusions:
We have proposed a simple method for 3D primitive detection from a single image. A demonstration is shown in Fig. 3 (Figures 4-7 show few more results). The histogram of slopes of the contours belonging to the object image and the Shape from Shading technique to extract the depth information were the important steps in the algorithm realization. Topological connectivity-based fusion of faces was used to further improve the results. In the future, the parameters of the primitives could be extracted after the initial detection is done. This could then be used to perform a 3D reconstruction of the object. Another possible application could be a CBIR system which uses the primitive information to look for matches in a database of CAD objects.

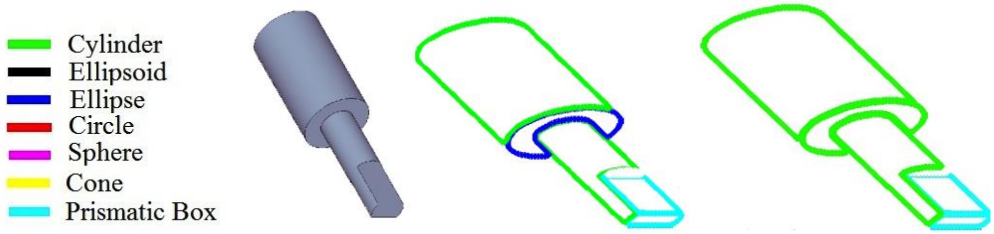

Fig. 3: Here is a sample result from the Engineering Shape Benchmark (ESB) database. : (a) Color Code to interpret results, (b) Input Image, (c) Result without face fusion, and (d) Result with face fusion.

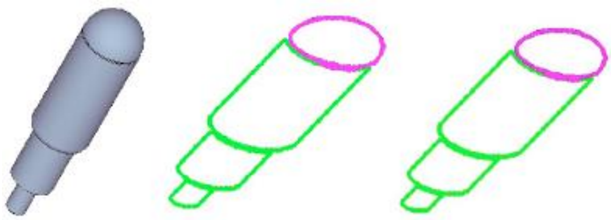

Fig. 4: Result for a stepped cylinder with spherical end.

Fig. 5: Result for a shaft-like model.

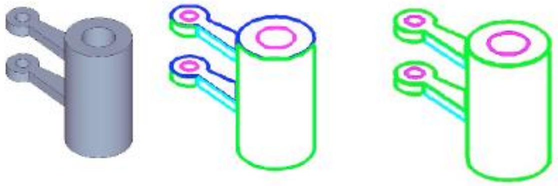

Fig. 6: Result for another test object.

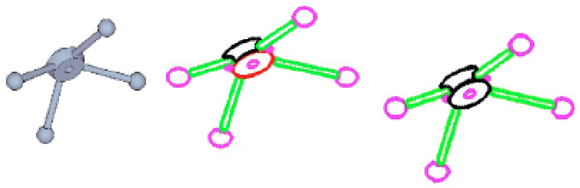

Fig. 7: Result for a lever-like model.

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