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Height-field construction using cross contours

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A B S T R A C T

We developed an interactive modeling tool for constructing a height field from the cross contours in a line drawing, added to provide an illusion of depth. Our approach places no specific constraints on the artist and can handle freely drawn shapes with partially structured or partially connected cross contours. In our system, the user first draws cross contours across the interior boundaries of the object. The system then extracts the intersection points of the contours and derives 2D polygons by connecting consecutive intersection points with straight lines. These 2D polygons are treated as the projection of a polygonal surface approximating the shape of the object. The 3D edge vectors and 3D normals of the approximated polygon surface are then estimated while considering the perceptions of the viewer and the goals of the designer. Based on the relative height values obtained from the 3D edge vectors and the co-planarities of the curve segments, a height field is generated in the image space that reasonably matches the cross contours of the input drawing. Experimental results demonstrated the ability of the system to generate height fields from a wide range of cross contours. We also showed that our system can be used to apply lighting effects to sketches and allows local shape deformation based on the constructed height field.

1. Introduction

Cross contours are drawn lines that cross the form of a depicted object [1] to represent the three-dimensional form of the object being sketched. As shown in Fig. 1, cross contour drawing employs grid-like patterns that simulate the 3D polygonal meshes approximating the objects. Inspired by the analogy with the wireframe rendering of a polygonal meshes, these cross contours provide a guideline for constructing the underlying surface of the object depicted. In contrast with wireframe rendering, however, cross contours are partially structured or partially connected curves. There are no specific restrictions on the way in which different artists apply cross contours.

In this study, we propose an interactive modeling tool that allows constructing a height field from a cross contour line drawing. In our system, the user draws cross contours over the regions bounded by the object's boundary contours in partially structured or partially connected forms (Fig. 2(a)). Using this hand-drawn sketch, our system then constructs a smooth height field (Fig. 2(b)), which can be used to generate a range of lighting effects (Fig. 2(c) and (d)) or to deform the local shapes of the depicted object. The main technique underpinning our method is the conversion of the cross contour drawing to a 2D polygonal network, which is then unprojected into 3D space using image space optimization. In particular, our method uses the image space as a common parametric domain for optimization, allowing a smooth height field to be constructed from the partially structured or partially connected cross contours. To the best of our knowledge, our system is the first to create a height field from a 2D hand-drawn sketch using cross contours. Since the proposed approach paces no specific constraints on the cross contours used, the artist is free to draw any shape using their preferred style of cross-contour line drawing.

1.1. Related work

Our approach is closely related to sketch-based approaches for generating normal maps or height fields from single-view sketches [2–8]. These methods are commonly used to apply 3D-effect shading to sketched objects. Inspired by concepts from industrial, CrossShade [5] and BendFields [3] used cross-section curves as the user inputs. This is suitable when representing the shape of a well-structured industrial product but is inadequate when the object represented has an unstructured organic form. The method proposed by Bui et al. [4] used a hatching-stroke approach for computing the surface normals of the depicted object. While this is able to handle unstructured forms and control interior region normals, approaches using only surface normals [2–5] provide only

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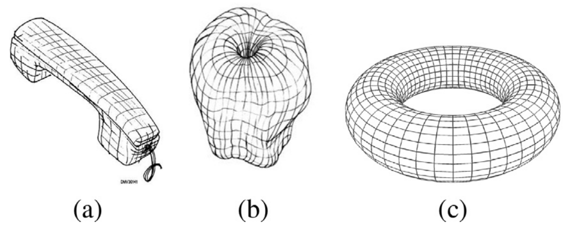

Fig. 1. (a) A well-structured form and (b) an organic form represented by cross contours; (c) wireframe of a torus.

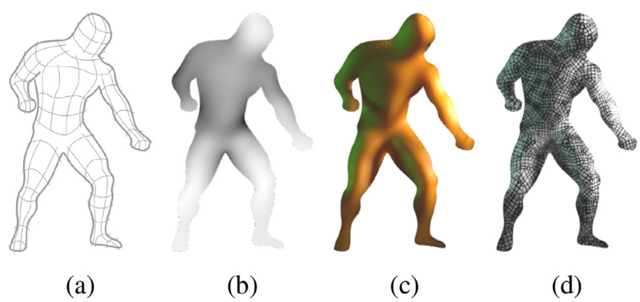

Fig. 2. (a) Input sketch; (b) height field; (c) global rendering; (d) texture-mapping.

simple shade effects. Although a height map can be constructed by integrating a normal map [9], the result appears unnatural from other viewpoints, as a specific height value is normally used as a fixed boundary condition. Ink-and-ray [6] returns a height field in bas-relief form, allowing global illumination effects in animation sequences. However, the height field generated using bas-relief is blobby and is only acceptable from a sketching viewpoint. Xu et al. [7] used isophotes and shadows to compute normals and height fields from different types of sketches. In contrast with our approach, in their method, the artist requires detailed training on the depiction of shapes using isophotes and shadows. Ecker et al. [8] proposed a method for generating depth values from the projection of planar curves onto an object. The input to this system looks very similar to ours since planar curves are drawn across an object and their intersections are important inputs to the system. However, their technique estimated depth values by recovering planes that intersect with the surface along the planar curves, and the forms of these curves are too irregular to allow the structure of the polygons to be extracted.

Human visual perception of parallel curves and the intersections between two crossing lines provide important rules which to base the reconstruction of 3D information from a surface [10–14]. Andre et al. [11] generated a 3D surface from two groups of parallel strokes that resemble cross contours. Instead of requiring the cross contours to be drawn, parallel strokes were automatically generated from the hatching lines drawn by the user and placed regularly on the surface. The approach by Andre and Saito [12] used two orthogonal cross-sections to model 3D objects, generating regular cross sectional planes internally. True2form [7] uses parallelism and the local orthogonality of curves to construct the 3D model. This method places hard constraints on input sketching, based on design principles, and is only suitable for constructing well-structured objects that are the standard objects in industrial design.

Instead of focusing on 2D curves, several studies focus on constructing surfaces for objects that are depicted by a set of 3D curves [15–17]. Taking curve networks on possibly non-parallel cross sections arranged in a 3D space as an input, Liu et al. [15] proposed a method that can reconstruct full 3D surfaces for objects comprising of multiple separate components. The method requires separate regions belonging to different parts on each cross section to be labeled before the curve network is interpolated using a divide-and-conquer strategy. Using only 3D boundary curve cycles specified by a user, Bessmeltsev et al. [16] generated the corresponding quad-mesh by constructing a network of quadrilateral cycles. A key point in this study is the algorithm that automatically segments a curve cycle into pairs of matching flow-lines, from which the network of quadrilateral cycles can be built. Pan et al. [17] suggested a method that ensures the agreement between the principal curvature direction field of the constructed surface and flow field interpolating the flow-line curves extracted from user-drawn curves. Their system takes the same input as that reported previously [16] but automatically classifies it into flow lines and trimming curves before constructing the corresponding surface using an iterative approach. Although all these methods can generate a high-quality full 3D model, they either need special equipment such as freehand ultrasound or an MRI scan device [15] or require multi-viewpoint modeling interfaces [16,17]. With respect to helping designers to shade a 2D sketch, our system can support this task more efficiently using user inputs that are easier to draw.

In our method, we use bivariate scalar data such as a height field to represent a 2-manifold surface with a boundary in 3D space [7,18,19]. This type of representation has a regular structure as its parameter space, which enables many image processing algorithms to be adopted for processing the geometry (e.g., filtering, compression, and feature detection) [20]. By cutting a surface and parameterizing it onto a square, Geometry image [20] converts a surface of arbitrary genus into bivariate geometric data storing 3D positions as an image, which has the advantages of a completely regular structure in many applications such as rendering and compression. In this study, we utilize the image as a common parametric domain for optimization to obtain a smooth height field from partially structured and partially connected cross contours.

1.2. Contributions

The main contributions of our study are as follows:

- *A novel method for constructing a height field using cross contours*: Our system uses cross contours as a metaphor for constructing a height field from a 2D hand-drawn input. In contrast with approaches using other sketching tools [5,7,13], it allows users to draw sketches without following hard constraints or requiring special knowledge of the drawing of primitives.
- *Unprojection of 2D polygons into 3D space by image-space optimization based on the properties of polygons*: Inspired by the analogy between cross contours and a polygonal mesh, we treat cross contours as the projection of a 3D polygonal mesh approximating the depicted shape. Our system uses image-space optimization to obtain the 3D edge vectors and 3D normals of polygons. This allows the system to produce realistic height fields for objects of arbitrary shape and frees the user to draw cross contours with unstructured or partially connected forms.
- *Height field construction without fixed boundary conditions*: Instead of using specific values as constraints, we constrain the relative heights of the intersection points of the cross contours. As the height field has no fixed boundary conditions, a more natural height field can be obtained that maintains its realistic appearance from multiple viewpoints.

2. Overall process

In our system, we use the 2D point grid as the common parametric domain for optimization, allowing the construction of a height field from the unstructured or partially connected cross contours. Let Ω denote the grid point domain. Height field $\mathcal{H}$ is