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Stroke-Based Surface Reconstruction

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Abstract. In this paper, we present a surface reconstruction via 2D strokes and a vector field on the strokes based on a two-step method. In the first step, from sparse strokes drawn by artists and a given vector field on the strokes, we propose a nonlinear vector interpolation combining total variation (TV) and H^1 regularization with a curl-free constraint for obtaining a dense vector field. In the second step, a height map is obtained by integrating the dense vector field in the first step. Jump discontinuities in surface and discontinuities of surface gradients can be well reconstructed without any surface distortion. We also provide a fast and efficient algorithm for solving the proposed functionals. Since vectors on the strokes are interpreted as a projection of surface gradients onto the plane, different types of strokes are easily devised to generate geometrically crucial structures such as ridge, valley, jump, bump, and dip on the surface. The stroke types help users to create a surface which they intuitively imagine from 2D strokes. We compare our results with conventional methods via many examples.

AMS subject classifications: 65K10, 65D18, 65D17

Key words: Surface reconstruction from a sparse vector field, augmented Lagrangian method, two-step method, curl-free constraint, total variation regularization, preservation of discontinuities in surface normal vectors.

1. Introduction

Sketch-based interfaces for modeling (SBIM) has been substantially explored by many researchers because of efficiency and intuitiveness, from the early systems like SKETCH [1] and Teddy [2] to recent SmoothSketch [3] and FiberMesh [4]. A thorough review of SBIM systems can be found in [5]. Without lighting or shading cues in photometric stereo [6–8]

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or shape-from-shading [9, 10], or geometric constraints defined by 3D curve network [11], the task of 3D model reconstruction from 2D line drawings is more challenging than image-based 3D reconstruction. A lot of research results have been achieved towards this challenging task based on contours [2], hidden contours [3], symmetric sketch pairs [12], and structured annotations [13]. The models created by these systems are limited in structures of shape. Moreover, surface details such as the crease structure are not considered in these systems. Note that the crease structure can be added by surficial augmentation techniques [14]. Motivated by the above mentioned works, we are targeting at a sketch-based modeling system which can model complex 3D objects with simple sketches. As the first attempt to this direction, we present our research achievement on surface height reconstruction via 2D strokes and a vector field on the strokes.

Many surface reconstruction algorithms from surface gradients [15–18] enforce the integrability for producing correct surface heights. For single-view modeling, the authors [19] used a constrained optimization with many types of geometrical constraints. The authors [20] showed that the method in [19] requires a lot of user interactions to provide enough constraints for modeling a desirable surface. Another single-view modeling system [21] used a close form method to reconstruct curved 3D surfaces based on apparent contour, inflation constraints, and normal specification in the parameter space. Recently, the authors [22] highlighted that the algorithms in [19–21] have difficulties in solving three problems in surface-from-gradients: handling sparse gradients, preserving sharp features, and preventing surface distortion. To solve these problems, Gaussian kernel approach without discrete integrability enforcement is used in [22]. Our proposed method is also capable of handling these problems because of TV regularization and curl-free constraints imposed in a nonlinear vector interpolation. On the top of this, we provide a very fast and efficient algorithm to solve the proposed energy functionals via augmented Lagrangian method [23].

Based on the observation that humans are good at assigning local surface normals for specifying local shape [24], the authors in [20, 25] achieved stroke-based surface reconstruction in two steps. In the first step, dense surface normals are obtained from sparse vectors on given strokes via linear vector interpolation methods. In the second step, the dense normals are integrated for reconstructing a height map. In LUMO method [25], a method of interpolating vectors is based on so-called Telegrapher's equation (the damped wave equation). In ShapePalettes [20], an energy functional minimization is used and the main mechanism of interpolation is based on a parabolic type partial differential equation (PDE) with the fourth order term related to a surface curvature. The advantage of LUMO and ShapePalettes methods is that the governing equations are linear PDEs so that standard efficient numerical solvers such as the multigrid method or the fast Fourier transform (FFT) can be applied. However, the disadvantage is that both models are based on the Laplace operator which strongly enforces the smoothness in interpolated vector field. That is, the assigned vectors on strokes are diffused into the whole domain and then eventually averaged out in the final steady state. Therefore, interpolated vector fields from LUMO and ShapePalettes simply yield smooth surfaces; see Figs. 12 and 13.

The pioneering work for surface reconstruction from sparse information based on an