Illustrative Visualization of Endoscopic Views

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Abstract. This paper deals with the application of illustrative line renderings on endoscopic views. We examine different line drawing concepts and assess the ability to represent interior branches as well as specific anatomic features. Furthermore, we conduct a qualitative evaluation to rate the results of different illustrative visualization methods. We evaluate how well branches are depicted according to a shaded object and which of the technique is rated as the most expressive. We use different anatomical surfaces which were derived from clinical image data. Moreover, we identify the limitations of the illustrative visualization and derive requirements for the application.

1 Introduction

Virtual endoscopy is utilized for the examination of air-filled or fluid-filled structures, such as colon, blood vessels, kidney, bladder, larynx, paranasal sinus, and so forth to present endoluminal views. While real endoscopy involves anesthesia and is involved with some risk, virtual endoscopy may partially replace this procedure and increase patient safety. Virtual endoscopy is restricted to intensity data from CT and MRI instead of the full-color information in real endoscopy. Despite this problem, pathologies are detected in modern virtual endoscopy systems with a high sensitivity. Mostly, the virtual endoscopy is used for screening colorectal cancer or bronchogenic carcinoma. The virtual endoscopy surface models can be reconstructed by clinical image data such as CT data. Often, the endoscopy is used for examination and for detection of polyps, tumors, calcified plaques, and stenosis. Especially for lectures for the doctors-to-be it is interesting to illustrate polyps, tumors, or plaques as known from anatomical atlases. There, only essential information are depicted while unnecessary ones are avoided to prevent visual clutter. Therefore, illustrative visualization has a high potential in medical applications such as surgery planning [1] and intra-operative visualizations [2]. In this paper, we focus on illustrative surface renderings. We introduce different line drawing concepts and employ them to endoscopic views. This idea is motivated by its high potential to depict interesting objects in normal shading and illustrate surrounding non-essential context objects with line drawing techniques or vice versa. Line drawing techniques attempt to convey the surface by drawing several lines. Here, we distinguish between feature lines and hatching. While feature lines try to depict only salient regions by separate lines, hatching uses a bunch of lines to illustrate the object. First, we show that current feature line methods are not able to illustrate the endoscopic view let alone to convey a spatial impression, whereas hatching methods are able to depict the spatiality. Here, we focus on the hatching method by Praun et al. [3] and Zander et al. [4]. Furthermore, we use the *ConFIS* method by Lawonn et al. [5], which can be seen as a hybrid between feature line and hatching. We give an overview about the presented methods in Section 2. The contribution of this paper is to examine the application of line drawing techniques to endoscopic views. We present feature line methods and hatching techniques. We show that feature lines are not appropriate for endoscopic views. Furthermore, we introduce hatching methods. Moreover, we conduct a qualitative evaluation to assess the proficiency of these methods in order to gain a spatial impression of endoscopic views in comparison to surface shading.

2 Material and Methods

This section gives an explanation about the underlying surface data sets as well as a brief overview about the line drawing techniques that we want to evaluate.

2.1 Endoscopic Data

We use clinical image data such as CT or MRA to acquire the anatomical information as well as the surface model. We reconstruct the surface mesh by applying a simple thresholding segmentation followed by a connected component analysis. The resulting segmentation mask is used to construct the surface by a marching cubes algorithm. Afterwards, the mesh quality is improved by a combination of edge collapses, edge flips, smoothing, and remeshing.

2.2 Methods

First, we present some feature line methods and explain the key idea.

Feature Lines: There are several feature line techniques: *ridges and valleys* [6], *suggestive contours* [7], *apparent ridges* [8], and *photic extremum lines* [9]. These methods are explained in more detail in [10]. *Ridges and valleys* are defined as the loci of points where the principle curvatures reaches an extremum in the principle curvature direction. As *ridges and valleys* are not view-dependent, *suggestive contours* attempt to resolve this issue. *Suggestive contours* extend the normal definition of the contour. These lines are defined as the set of points where the diffuse lighting reaches a minimum in the direction of the projected view vector. Unfortunately, objects without concave regions have no *suggestive contours*. In contrast, *apparent ridges* are a view-dependent approach that tries to depict also features which are missed by *suggestive contours*. *Apparent ridges* extend the definition of *ridges and valleys* by using a view-dependent approach. It defines view-dependent curvatures as well as view-dependent principle curvature directions. Hence, *apparent ridges* are also defined as the set of points where these

(a) Shading (b) RV (c) SC (d) AR (e) PEL

Fig. 1: Endoscopic view rendered with simple shading (a), *ridges and valleys* (RV) (b), *suggestive contours* (SC) (c), *apparant ridges* (AR) (d), and *photic extremum lines* (PEL) (e).

curvature assumes an extremum in these directions. Last, *photic extremum lines* are the loci of points where the variation of illumination in its gradient direction is a local maximum. Figure 1 illustrates that these methods are not appropriate for endoscopic views. In [10] this result was also confirmed at the trachea model.

Hatching: We consider three different techniques: the method by Praun et al. [3], Zander et al. [4], and Lawonn et al. [5]. All three methods use an underlying curvature direction field. For this, we build a curvature field according to Rusinkiewicz [11]. He approximates the second fundamental tensor by linear differences of the vertex normals and least square methods. Afterwards, the determination of the eigenvalues and eigenvectors of the second fundamental tensor yields the curvatures and the principle curvature direction. Praun et al. introduced *real-time hatching*. They generate line-art tonal art maps for different shading levels. Afterwards, lapped textures are applied to map the line-art textures onto the surface. Thereby, the textures are mapped randomly onto the surface and missing facets are processed by querying a list of non-covered facets. Then, those textures are used which correspond to the underlying shading. Zander et al. employ *high-quality hatching*, a geometry-based method. They do not use textures, but streamlines. These streamlines are generated on the entire surface and propagated along the principle curvature directions. The shading of each streamline part corresponds to the underlying surface shading. Lawonn et al. developed *ConFIS*. This method seeds only streamlines at relevant regions determined by the mean curvature and its gradient. They define a contour margin and feature regions. These regions are relevant for streamlines. The streamlines are traced along the principle curvature directions. Seeding streamlines at certain regions yields a faster approach than a generation on the entire surface.

2.3 Evaluation

We performed a qualitative evaluation of the three line drawing techniques to rate the ability for assessing the spatial impression. For the evaluation, four surface models were chosen. The evaluation was conducted with seven researchers who are familiar with medical visualizations. We generated the illustrations and showed the results in different order. The sequence of the data sets was the same. The ordering of the line drawing techniques changed. First, we showed the researchers different results and asked them if they are able to perceive branches and other features from the resulting pictures. After all illustrative pictures were shown, we presented the normal shaded image. Then, we asked if they would have expected this model. Afterwards, we showed all results to compare between the different methods. Here, we wanted to figure out if some features were misinterpreted or missed. In comparison of all line drawing methods with the shaded model, the participants should rate which technique is more appropriate to capture salient regions as well as the spatiality and which limitations they noticed. During the evaluation, we noted the spoken comments by the participants.

3 Results

In Figure 2 the shaded models are shown. For each model the results of the different hatching methods are depicted. The results of our evaluation are summarized in Table 1.

	Real-time	High-quality	ConFIS
1	4	0	6
2	2	0	6
3	5	0	2
4	1	0	7

	Real-time	High-quality	ConFIS
1	5	5	7
2	5	7	7
3	7	7	7
4	6	6	6

Table 1: The left table shows which method was rated as most effective for the four data sets (left column). The participants could also vote for two techniques (maximum is seven). The right table shows how many participants counted the right number of branches.

We assessed two findings. First, which technique was rated as most expressive and second which method delivers a good result for perceiving the right number of branches. The spoken comments of the participants were mostly the same. The *real-time hatching* (*RT*) gives a good spatial impression, whereas the *high-quality hatching* (*HQ*) is insufficient for a 3D impression. The *ConFIS* is also able to deliver a spatial impression and tries to depict salient regions. Especially for the third model, the cut-off between the two branches was illustrated appropriately. In contrast, the *HQ* could not depict it well. Furthermore, the participants liked the consistent drawing of the *ConFIS* method. Whenever a branch is depicted, the lines wrap around the outgoing structure. The *RT* technique is able to illustrate the model according to the light intensity. Therefore, the result is very close according to the shaded image. Two participants realized some distortions of the *RT* method as this is a texture projection method. We implemented the

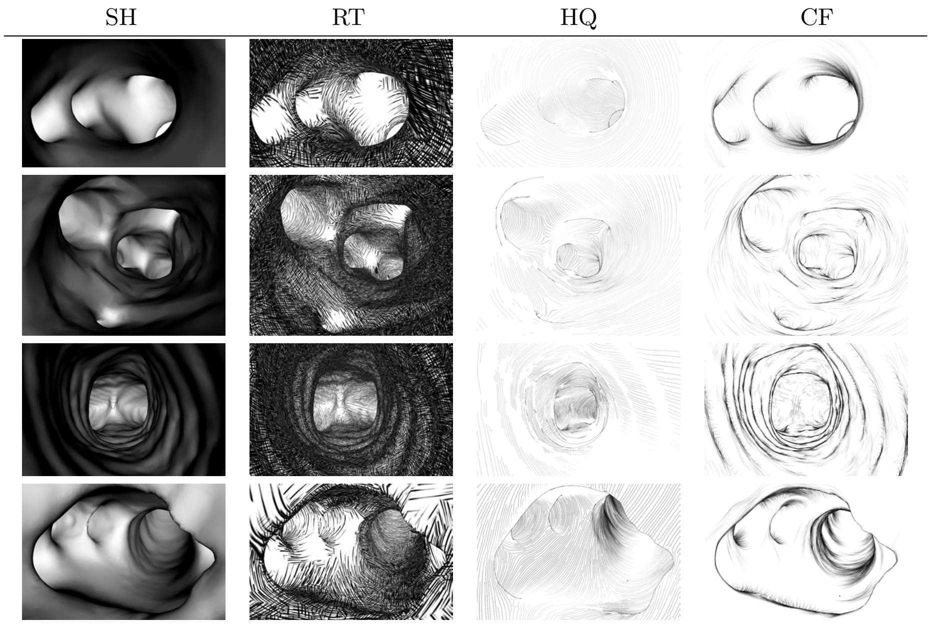

Fig. 2: Endoscopic view illustrated in simple *shading* (SH), *real-time hatching* (RT), *high-quality hatching* (HQ), and *ConFIS* (CF).

method but used another parameterization technique. Nevertheless, they mentioned that these artifacts were not distracting to focus on the object branches. One participant thought of an improvement of *HQ* and *ConFIS* by attenuating the lines according to the distance to gain better depth cues. In summary, the *ConFIS* technique was rated as the most expressive technique and gives the best impression for branches.

4 Discussion

The result of our evaluation can be summarized such that all methods are able to illustrate the underlying surface model. The *RT* method uses the underlying shading to create an illustrative visualization result which is close to the shaded image. The *HQ* technique generates streamlines on the whole surface and shades them according to the underlying illumination. In comparison to their method, the *ConFIS* technique used a different method. Here, this method depicts the spatiality by illustrating the contour margin as well as curvature-based features. Therefore, if the user demands a salient representation with a spatial impression, we recommend the *ConFIS* method. For a full visualization of the object and using an alternative to diffuse lightning, we would recommend the *RT* method. As the method by Praun et al. uses a projection of the texture onto the surface, it is sensitive to surface noise and the results depend strongly on the local parameterization. To avoid distortions, the mapped texture should be small to prevent a covering of a large high frequent surface. This implies a longer preprocessing time for determining the lapped textures and a result which is close to normal shading. *HQ* and *ConFIS* depend on the underlying curvature field. The presented curvature field by Rusinkiewicz is robust against surface noise. Here, we notice that the *ConFIS* method is faster than the high-quality hatching. This is explainable by the fact that *ConFIS* draws only streamlines at salient regions and therefore less streamlines than the high-quality hatching. Surprisingly, all methods were able to illustrate noised surface well. This can be seen from the second data set of our evaluation. Regarding our evaluation, we can state that hatching methods are able to offer an alternative to normal shading. They can be used for context-aware medical illustrations in endoscopic views as well as learning illustrations for textbooks.

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