An review of line extraction and edge detection methods

CLAUDIOUS TIRIVASHE NHEMWA, University Of Cape Town, South Africa

In this research we review the methods used for feature extraction on 3D models. The advancement of 3D scanners which are now used to document existing structures. These scanners produce models that have a variable noise output hence the need for a method that is robust and efficient. Noise affects most models making them obsolete for scanned models which noisy most of the time. Literature proposed by expects in the field show that it is a difficult task to have to have a method that performs well on all models. Further research is required in finding robust and accurate methods though great strides are being made in that regard. This paper analyses edge detection method and then moves to feature line extraction methods. Edge detection comes before feature line extraction and most feature line extraction methods are built on edge detection.Tensor voting methods excel best with noisy images and hybrid models for edge detection hence those are the recommended methods by this paper.

CCS Concepts: • **Computing methodologies → Mesh models**; • **Graphics**;

Additional Key Words and Phrases: 3D Modelling, line extraction, Meshes, edge detection

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1 INTRODUCTION

The growth of the 3D scanning and modelling industry in the last 20 years has led to the need for different strategies to analyse, create and process 3D models. Scanning structures has become one of the best ways to document existing objects and structures. High precision cameras and scanners are calibrated to extract data from the sites and structures. Different strategies are used in the scanning process with a combination of aerial photographs and terrestrial photographs or even full airborne 3D scanning . The Zamani project [12] uses this technology to document and preserve heritage sites. The scanned models are then archived and stored creating a huge database of models which can be processed in a later stage. Most scanned models contain some kind of noise in them and this noise proves to be a nuisance in the analysis stage. Xianfang et al [17] defines noise as data that is all over or disorganised points. Plenty of research has been done to formulate algorithms remove noise from models. These methods are utilised in edge detection and feature extraction.

Author's address: Claudious Tirivashe Nhemwa, nhmcla003@myuct.ac.za, University Of Cape Town, P.O. Box 13914, Cape Town, Western Cape, South Africa, 7700.

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Outputs from scanner can be in the form of two types : point clouds and 3D meshes. Point Clouds are a group of points in a 3D space and they are produced from structured light scanning (SLS) and Time of Flight (TOF) techniques[22]. 3D meshes are models built using polygons and that uses the x,y,z coordinates for the height, width and depth. In this paper we focus on methods that are used for 3D meshes.

In the case of the Zamani project the heritage sites are old hence their conditions are variable which affects the output of the scanners. There is a need to find efficient algorithms to extract 3D meshes feature lines efficiently hence the need for a robust and accurate method. Feature lines are used in mesh remeshing[1] , surface segmentation [18] and non-photorealistic rendering [3]. Feature lines also help in smoothing of 3D models and detecting changes in the structures overtime. These changes might occur because of natural disasters such as earthquakes , volcanoes and even human interference hence with feature lines these changes are easily detected.

In this paper we investigate methods used for edge detection and feature line extraction with analysis on their suitability on models with variable noise levels. Firstly, we look at edge detection methods and separate them in to two categories [23]: edge based and face based methods. Secondly, we then look at feature line extraction methods. Edge detection comes before feature line extraction with most method used in edge detection being used for line extraction. .

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2 TYPES OF EDGES

The edges of models are separated into two categories : smooth edges and sharp edges. Lee et al[23] defines sharp edges as meshes or points in which the change in the normal vector is abrupt and in smooth edges the change is constant. Sharp edges make it difficult to extract feature lines due to the large gradients which leads to noise [7]. The processing of these sharp edges has become an important task especially in scanned 3D models.

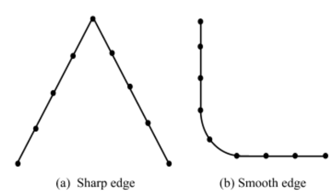

Fig. 1. Types of edges [23]

3 EDGE DETECTION

Edge detection [2] produces outlines of structures and the margins of the objects. This stage usually comes before feature line extraction and reduces the amount of data to be processed for later stages.Lee et al [23] separates edge detection into two categories : edge based and face based methods. Face based methods creates regions that are separated by the geometric properties such as the curvatures. In edge based methods scanned points are used to detect discontinuous edges.

3.1 Edge based Methods

Amer et al [2] analyses the different edge detection methods such as Sobels operator,Prewitt's Operator, Laplacian of Gaussian and Robert's Cross Operator. Sobel's operator uses approximation for smoothing and calculates the gradient in all directions. The output of the Sobel's operator is sensitive to noise and produces thick lines. Prewitt's operator is similar to Sobel's operator as it uses gradients however it is faster method for edge detection though it works well on noiseless models only. Laplacian of Gaussian uses the noise to signal ratio with Gaussian function to smoothing the model and the laplacian operator uses second derivatives to detect edges. The paper then proposes a method which is adapted edge detection in dark images. This method was tested and results were shown but the no metrics were used in checking the efficiency of the method or a comparison of the methods. However, this method could be useful in models that do not come out as planned and have a dark portion.

Canny [6] proposed a method which uses adaptive thresholds , in which the thresholds are adjusted according to the noise ratio. A noise estimation algorithm was proposed in order to derive the required threshold. It used the Gaussian function for smoothing of the model. This method uses derivatives on gradient and uses the zero crossing method to extract edges. The paper by Canny [6] did not assure the reader on the performance of the method hence the it may be inefficient under noise. In addition , the method can not handle corners hence a limitation which makes it inefficient in detecting 3D models and the model can not compute if there are multiple edges as it difficult to make a decision on the which line to output. Canny's method detects a single point as a edge without checking the difference to its neighbors hence giving inaccurate output.

3.2 Face based Methods

Belsea at el [4] at proposes the use of a surface segmentation algorithm to detect edges. The method does not require any predictions about the meshes hence it use the contents of the model. It uses piece wise-smooth model which performs well on noisy models and sharp edges. The method was tested using 40 images and it indicated positive results. In the paper the method was not tested for robustness and accuracy hence no quantitative data was used to reach the results.

3.3 Hybrid Methods

As edge based methods are prone to inefficiency when there is noise but perform well when the mesh is smooth and regular. Face base approaches are robust and accurate under noise however less efficient on smooth surfaces.[23] proposes a method that combines the two approaches.

The polygon-based edge-detection [23] uses area and angles to detect edges. The paper compares it to the principal curvature method and it is shown that the method performs better on noisy meshes. The method detects both smooth and sharp edges however on smooth edges it gives a similar performance to the principal curvature method.

Genetic algorithms which use a part solutions to formulate a global solution. Bhandarkar et al [5] proposes a genetic algorithm for edge detection in which uses a cost minimization approach. The method uses two operators: mutation and crossover. Mutation operators use the data on edges to lead to convergence . The paper compares the proposed algorithm with other methods to test its performance. It performs well under noisy inputs and produces quality output. In order to improve the methods various operators where tested on it such as the meta-level operators.

Xie et al [20] propose using Convolutional Neural Networks(CNN) to detect edges which are designed to learn features and be multiple scale responsive. The methods uses 16 neural networks that are pre-trained.

Shih et al [15] propose a method that uses gradient and a wavelets to detect edges. The combination gives a method that suppresses noise and detects the other points. Edge tracking is then done on the model which joins the edges that are not connected.This methods is not able to distinguish a points that not connected to the rest of the model because of edge tracking. The methods fails to to detect edges that are close and images with high noise levels prove to be difficult for the method.

4 FEATURE LINE EXTRACTION

4.1 Normal curvature-based methods

In normal curvature methods [11; 25] the curvature is estimated in the direction of the next point. The principal curvature is then calculated using eigin vectors which is efficient when the points are uniform. According to Rusinkiewicz [11] the normal curvature method can be adapted to handle different model by increasing the neighboring size which Yoshizawa et al [24] proposes the use differential geometry and inversion-invariant local surface-based.

In Rusinkiewicz's [11] paper uses higher derivatives and curvatures on surfaces. The focus of the paper is on robustness of the method however the results were affected by noise in the input. The algorithm was tested on a large scanned mesh and it produced positive results in reasonable time. The output of the algorithm were not compared to any other algorithm hence the results could not be analysed.

The differential geometry method proposed by Yoshizawa et al[24] is fast and processes 1-1.2M triangles a second. The method is 2-3 faster than Rusinkiewicz's method[11]. It produces result that accurate however noise seems to affect the method hence its not suitable for noisy models. Calculating coefficients required for the method proves to be difficult task however estimates can be used in place.

Yang et al[21] proposed a method to use principal curvature analysis (PCA) to detect curvatures. The method uses deferential invariants which are sensitive to noise hence they require denoising and smoothing of the model. The paper points out that they did not focus on making the algorithm robust in noisy data hence less work was put in the area. In order to work on noisy model a integral invariant [10] is used which estimates curvatures. Integration in itself has a smoothing effect hence it is robust in term of noise.

4.2 Tensor averaging methods

Kim et al[9] extends the original tensor voting algorithm by Gram Schmidt. The original method can detect sharp features and is not affected by noise however when it comes to smooth and clear models the algorithm fails. This weakness is resolved by using both the region growing technique and clustering. Shimizu et al [16] proposes a method similar to the latter which uses edge strength in instead of the vertex clustering operation. This makes Shimizu et al [16] method faster than the Kim et al [9]. Though it is faster its weaknesses are in detecting smooth transitioning boarders.

4.3 Morse theory

Vilanova et al[14] uses Morse theory for feature extraction which does not use derivatives and it is not affected by noise in its input. In this method cancellation is used to remove extra lines however it proved to be difficult to formulate a thresh-hold for cancellation. The method has a limitation of long lines which sometimes distort the output extraction lines.

Weinkauf and Gunther [19] uses Morse theory to extract salient edges which are visual aspects of the surface. Since the algorithm uses discrete mathematics it is not affected by issues that rise from derivatives such a noise. Lines are extracted as skeletons called topological separatrices. The problem with previous research on the method they disregard some salient edges however this paper tackles that problem by applying a concept of separatrix persistence.

5 DISCUSSION

The paper by Heath et al [8] compared the edge detectors and the output showed that the methods were affected by fixed parameters hence the need for calculation of these parameters to suit the input. As shown above Heath et al [8] supported the hypothesis that the methods were specialised hence making it difficult to find a one size fits all solution. In his rankings Canny[6] method hence it being widely used in the industry however improvements and adaptations have been made to improve it.

Many methods for edge dictation have been proposed with edge based methods being accurate and strong a detecting smooth edges while face based edges work well on noisy models. Lee et al [23] explains the different methods and proposes a hybrid method to which works well in most models.This combination of the two different methodologies gives the best results for models that have variable noise levels. Further research is required in the area especially with Artificial neural networks in the area could make the task less daunting.

The feature extraction methods have different qualities and strength with normal curvature methods [10; 11; 13; 21] being sensitive to noise and the Morse theory [14] can handle noise in models but its output is not guaranteed to be accurate all the time because of its line cancellation system. Tensor averaging methods [9; 16] perform well for noisy models but in smooth models and bad for smooth models.A trend appears of the different methods as they are good at processing a certain quality of models.For the problem tackled by this paper research is required in methods that are efficient an robust. However the tensor voting methods seem to be suitable for the problem proposed.

Our problem shows there is need for research for methods that can handle variable noise levels. This is because the noise levels are not guaranteed as different sites will mean different noise levels.

The table below rates he papers on their relevance and contribution. Noise tolerance refers to the effect that the level the method can handle noisy data. The following [4; 9; 16; 21; 23] are resilient to noise. Accuracy entails the quality of output that the method gives out. Lastly, the relevance refers to the contribution from the paper and its relevance to the problem. The ratings are separated by a 3 point scale : low, medium and high.

Paper	Noise Tolerance	Accuracy	Relevance
Rusinkiewicz[11]	1	3	3
Lee et al [23]	3	2	2
Shimizu et al [16]	3	2	3
Kim et al [9]	3	1	2
Canny [6]	1	3	3
Vilanova et al[14]	3	2	2
Amer et al [2]	1	3	3
Yang et al[21]	3	1	1
Belsea at el [4]	3	3	2
Xie et al [20]	2	2	2

Table 1. High = 3, Medium = 2, Low = 1

6 CONCLUSION

In this literature review we focused edge detection methods and feature extraction methods. The different methods excel in different scenarios and most have a niche or a type of models they handle best. Noise levels is the biggest parameter that required when selecting a method. We can conclude that edge detection hybrid methods produce the best results considering our noise levels are variable. Lee's [23] methods In feature extraction Tensor averaging methods excel best in noisy images hence they would produce the required output. fits the required with consistent result through different noise level. Testing method further is required in order to be certain it is the best method.

Further research is required in improving these different methods. The Convolutional Neural Networks method [20] could prove to be a big space to venture into as it has massive potential to be better than other methods. Research on the comparisons of these different method is required and further testing of the methods.

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