Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.18576/amis/110216

An Improved Space Characteristic Analysis Algorithm for 3D Model Information Hiding Based on Profile Analysis

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Received: 18 Oct. 2016, Revised: 26 Jan. 2017, Accepted: 28 Jan. 2017
Published online: 1 Mar. 2017

Abstract: Considering the practicability and simplification of space-domain pre-processing for 3D model information hiding, we present an improved carrier pre-processing using interval analysis of values on z-axis for the vertical profile of 3D models. First, the 3D model is scaled and rotated disproportionately according to fixed size and angle respectively, and the vertical profile can be obtained by horizontal mapping. Second, the vertical profile is mapped into the two-dimensional coordinate system and the values on the vertical axis can be determined using a fixed step size. Last, the vertical values are converted into binary numbers with interval constraints according to the fixed threshold. By disproportionate scaling with fixed size, the algorithm can be effective against the scaling attack. According to the fixed rotated angle and step size, the data can be embedded in redundancy of the whole model and the algorithm can be robust against cutting. The experimental results illustrate that, being satisfied the characteristic of carrier, our algorithm is of stronger robustness against the random noise under 0.2%, re-meshing and non-uniform simplification compared with similar algorithms.

Keywords: information hiding, 3D models, two-dimensional maps, profile analysis.

1 Introduction

As an important research branch in information security, information hiding technology is always based on digital image, while it is less based on 3D models. With the development of 3D-related software and hardware, 3D models become more and more popular on the Internet. The main research content of the latest Information Hiding and Multi-media Security Conference of ACM (ACM IH & MMSec14 Workshop) involves the information hiding technology based on the irregular carriers such as the 3D models. The main research content of IEEEICP2013 also involves the information hiding schemes and the media characteristics extraction and analysis for some carriers such as the 3D models. The research contents for the information hiding scheme in CCNIS2014 and CTCTS2014 focuses on the analysis and pre-processing for irregular carriers. With the continually development of 3D technology, 3D models will become important carriers. In China, the latest 12th national Information Hiding and Multimedia Security Academic Conference (CIHW2015), the information hiding technology of unconventional carrier becomes one of research emphasis, the 3D model will be the important carrier in the future, and it is very necessary to research information hiding technology based on 3D models.

Beginning from the pre-processing methods in space-domain for 3D models, this paper will hide data by changing the geometrical information spatially. The spatial domain methods are simple the oretically, but it is difficult to find the appropriate methods to improve their performance. Luo M. et al introduced the affine invariant with continuous analysis to optimize the vertex which will be replaced [1]. Du L. et al put the steady anchor into triangle orthocenter coding analysis, and the result will be the cluster elements to embed information [2]. Cai S. et al can determine the key position of models by the primary component analysis (PCA) and take it as the robust region, and use mesh segmentation method to improve the robustness and invisibility [3]. In literature [4], Wang K. et al put forward the volume moment based on continuous analysis, which enhances the robustness of algorithm

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against the connectivity attack. In literature [5], by rearranging the information presentation strategy of vertices and patches in the mesh file, Chung I. L. makes the algorithm has a large capacity. The information hiding technology based on the optical theory and method has several advantages, such as the multi-dimension, large capacity, strong robustness, and so on [6]-[7], so it is good at information hiding operation in spatial domain. It provides the theoretical basis for this algorithm of 3D that is generated by the space domain carrier processing in the calculation of integrated imaging system based on the intelligent depth inversion model, and also for the pre-processing method based on the structure characteristic of carrier in this paper.

Based on the advantages and disadvantages of space-domain algorithms proposed by other researchers, this paper will put forward a new information hiding algorithm based on the structure characteristic analysis of 3D models. In this algorithm, we select the profile of model, which is generated by the mapping into 2D space after horizontal rotating, as the hiding space, and use the coordinate value interval of function fixed step size to represent binary information. The data can be embedded in redundancy of the whole model after rotating fixed angle and function fixed step size, and with the fixed step size, and the model has been non-uniform scaled, so the stego model can be robust against geometric attacks. So this algorithm has strong robustness against geometric attacks. The performance of this algorithm is jointly decided by the horizontal rotating degree 3D model, function step size and redundancy strategy.

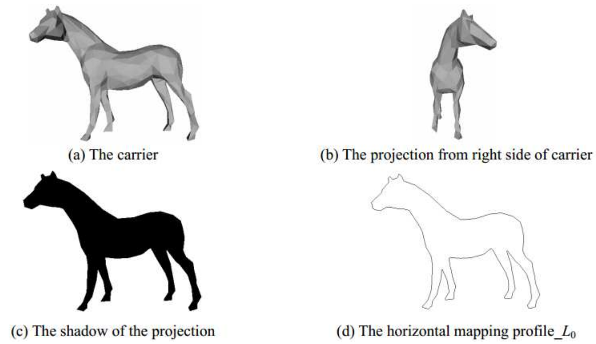


Fig. 1: The horizontal mapping sketch.

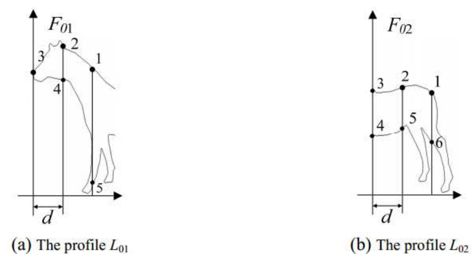


Fig. 2: The horizontal mapping of 3D models.

Table 1: Information transformation rules.

The interval threshold	Information transformation presence
$[kG/e,(k+1)G/e)$	0
$[(k+1)G/e,(k+2)G/e]$	1

2 Information hiding algorithm based on longitudinal profile analysis for 3D models

The information algorithm for 3D models based on longitudinal profile inflection points statistics can be divided into 11 steps:

Step 1: The data of 3D models which is the information hiding carrier will be read by the specialized software and adjusted on its size in order to make its length be equal to its height, and the adjusted model is denoted by G.

Step 2: The 3D models are mapped into the two-dimensional coordinate system after horizontal placement, and form the outline L_α. And L_α is the horizontal rotation angle, Fig. 1 shows the example when $\alpha = 0°$.

Step 3: The profile is segmented according to the half of width. For example, the profile L_0 is segmented into two profiles, one is denoted by L_{01}, and the other is denoted by L_{02}.

Step 4: According to the coordinate transformation, those two profiles after being segmented are separately denoted by $F_{\alpha 1}$, $F_{\alpha 2}$. Then L_{01}, L_{02} are converted to F_{01}, F_{02}.

Step 5: On the x-axis, the function $F_{\alpha 1}$ and $F_{\alpha 2}$ are polled according to fixed step size d, and their values on the vertical axis can be determined and denoted by $D_{\alpha 1}$ and $D_{\alpha 2}$. As show in Fig. 2, D_{01} and D_{02} are respectively the ordinate values of L_{01} and L_{02} by fixed step size d.

Step 6: The expression of function $D_{\alpha 1}$ and $D_{\alpha 2}$ are transformed using the interval rules, which is shown in Tab. 1.

Step 7: Compared with the hidden information, if they need to be modified, the corresponding value in the function $D_{\alpha 1}$ and $D_{\alpha 2}$ will be directly modified. At the same time, $D_{\alpha 1}$ and $D_{\alpha 2}$ can be embedded into the same data.

Step 8: After the step size f (which is the multiple of d), the hidden information are repeatedly embedded into $D_{\alpha 1}$ and $D_{\alpha 2}$. They are denoted by $D_{\alpha 1\_h}$ and $D_{\alpha 2\_h}$, h represents the number of repetitions.

Step 9: The 3D models that have been transformed after Step1 are rotated β angle according to the z-axis.

Step 10: Judge if the accumulative rotation angle on the z-axis is greater than or equal to γ, if it is, the previous information should be embedded repetitively. If not, we should execute from Step1 to Step10.

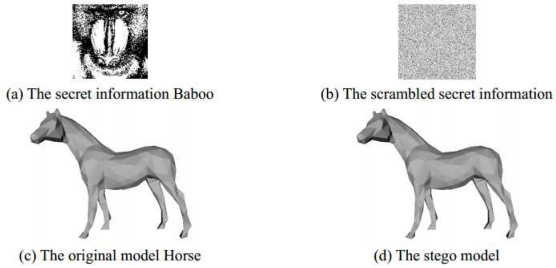


Fig. 3: The secret information and the experimental results.

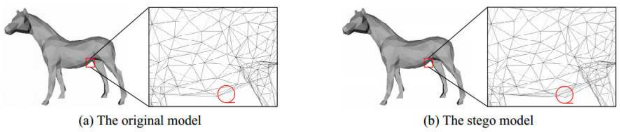


Fig. 4: The invisibility experiment.

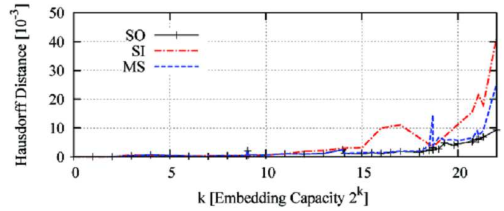


Fig. 5: Invisibility/capacity experiment (Hausdorff Distance-k).

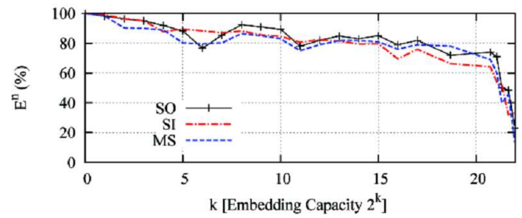


Fig. 6: Invisibility/capacity experiment ($E^n - k$).

Step 11: After embedding hidden information, the length, width and height of 3D models will be recovered.

3 Information hiding algorithm based on longitudinal profile analysis for 3D models

In this paper, we select Fig.3(a) as the secret information (128×128 binary image), and the scrambled one is shown as Fig.3(b). The 3D model in Fig.3 (c) is selected as the carrier, and Fig.3(b) is the stego model when $G = 512$, $d = 4$, $f = 32$, $e = 128$, $\beta = 5^\circ$, $\gamma = 90$, $h = 1$. The experimental environment includes VC++, OpenGL, and Matlab.

3.1 Invisibility and capacity

3.1.1 Human visual system

When $G = 512$, $e = 128$, we change strategy according to the interval. As shown in Tab.1, the maximum modified value is the distance for two pixels, which is far less than human visual judge distance. So the invisibility can be ensured. Fig.4 is a local amplification figure with two pixel distance as the modified value. We learned that the algorithm can satisfy the HVS characteristics, and the invisibility is well.

3.1.2 Hausdorff distance

By using Hausdorff distance [8], the visibility index is quantified. The Hausdorff distance between the original model and the stego model with Baboon is calculated by Metro. When the embedding quantity is 216bit, the Hausdorff distance is 0.000781.

The invisibility comparison experiment result of SO based on Hausdorff is shown in Fig.5, and the horizontal ordinate represents the embedding quantity 2^k, and the vertical coordinate is the Hausdorff distance. SI is the algorithm based on Skeleton Inscribed sphere [9], and MS is the algorithm based on Mean Shift [10]. Both of them were proposed before by us. From Fig.5, it can be seen that when the embedding quantity index $k < 15$, the Hausdorff distance of SO algorithm is less than it of SI and MS. While when $k \geq 15$, the Hausdorff distance of the SO algorithm is less than it of SI algorithm obviously, and a little less than the Hausdorff distance of MS algorithm. It can be proved that this algorithm has a better invisibility compared with SI- and MS-based algorithms. At the same time, the embedding quantity of SO is relatively large.

3.1.3 Skeleton Similarity

Fig.6 shows another invisibility comparison experiment by the Skeleton Similarity En. From Fig.6, it can be seen that the skeleton similarity of SI is better than it of MS. When $k \geq 8$, the skeleton similarity of SO is obviously better than it of SI. It can be proved that, this algorithm has better invisibility compared with SI- and MS-based algorithm, when the embedding quantity is large.

3.2 Robustness experiment

The secret information is hidden into the vertical coordinate values of projection profile, and the

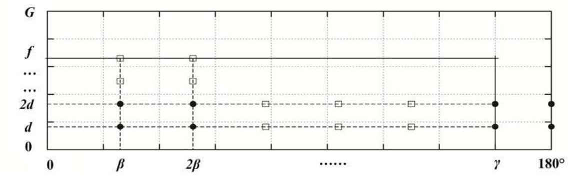
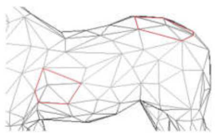
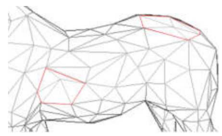


Fig. 7: The information redundancy embedding of SO.



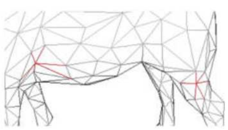
(a) The Stego model



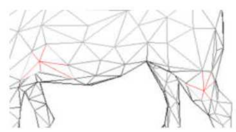
(b) The stego model under attack

(c) The extracted information

Fig. 8: Random noise (0.1%).



(a) The Stego model

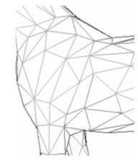


(b) The stego model under attack

(c) The extracted information

Fig. 9: Re-meshing.

(a) The Stego model



(b) The stego model under attack

(c) The extracted information

Fig. 10: Non-uniform simplification.

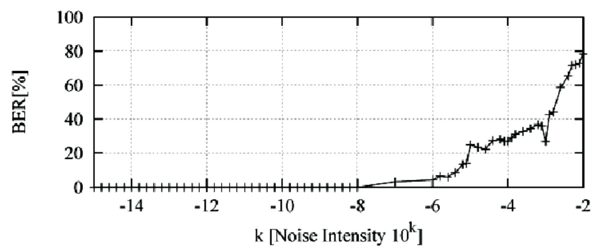


Fig. 11: The robustness experiment of random noise (BER).

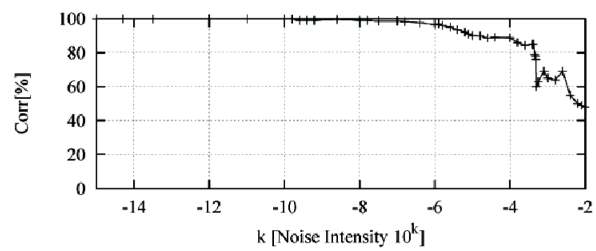


Fig. 12: The robustness experiment of random noise (Corr).

embedding strategy is that the data should be embedded in redundancy of three dimensions, shown in Fig.7.

In fact, the information is embedded into two regions, such as γ and f, G is a multiple of f, γ is a multiple of β, 180 is the multiple of γ. So the embedded information is distributed on the whole 3D models, and the redundancy distribution is uniform. So it can be effective against the attack of cutting picture percent. Because the length, width and height being fixed disproportionately in Step1, this step is still carried out when extracting. This algorithm can have strong robustness for any intensity scaling. The simulation experiments of the stego model under other kinds of attacks are shown in Fig.8. The robustness mathematical indicators include: (1) Extract the information bit sequence of BER; (2) Extract the Correlation coefficient of information bit sequence $\{s_n{}'\}$ and Original information sequence $\{s_n\}$, as show in Formula (1). Among, $\overline{s'}$ and $\overline{s}$ denote respectively the mean of $\{s_n{}'\}$ and $\{s_n\}$.

$$Corr = \frac{\sum_{n=1}^{N-1}(s_n' - \overline{s'})(s_n - \overline{s})}{\sqrt{\sum_{n=1}^{N-1}(s_n' - \overline{s'})^2 \cdot \sum_{n=1}^{N-1}(s_n - \overline{s})^2}} \quad (1)$$

The algorithm has good robustness against the random noise under 0.1%, the re-meshing and the non-uniform simplification as shown from Fig.8 to 10. Fig.8 (c), Fig.9 (c) and Fig.10 (c) are the extracted information after being attacked. The relationship between random noise intensity and BER and Corr is shown in Fig.11 and Fig.12.

The relationship between and BER, and uniform re-meshing intensity and Corr are shown in Fig.13 and Fig.14.

The relationship between uniform simplification intensity and BER, and uniform simplification intensity and Corr is shown in Fig.15 and Fig.16.

It can be illustrated from the above robustness experiments that our algorithm is of strong robustness.

Consider that the literature [11] and [12] represent the representative algorithm of transform domain and spatial domain in recent years, so put them as the comparative group. While compared with them, the robustness of this algorithm has been greatly improved, as shown in Fig.17.

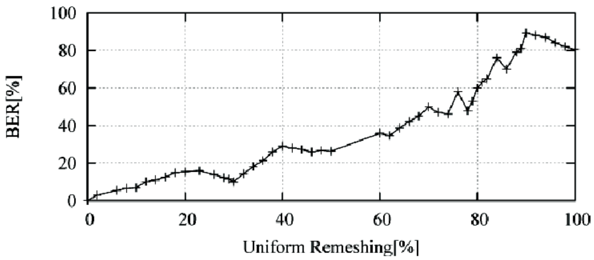


Fig. 13: The robustness experiment of Uniform Remeshing (BER).

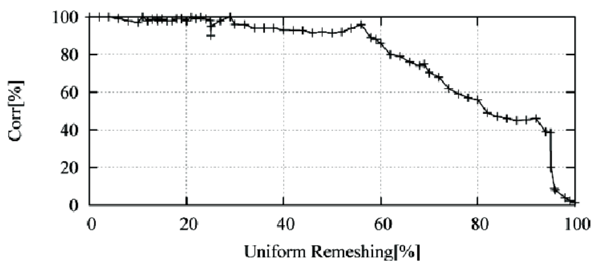


Fig. 14: The robustness experiment of Uniform Remeshing (Corr).

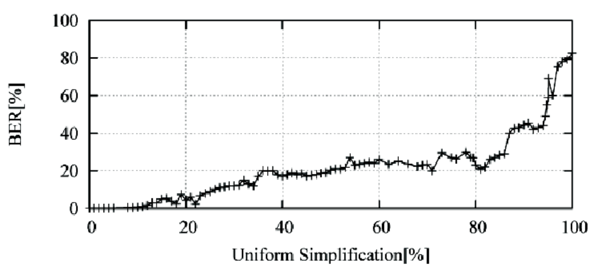


Fig. 15: The robustness experiment of Uniform Simplification (BER).

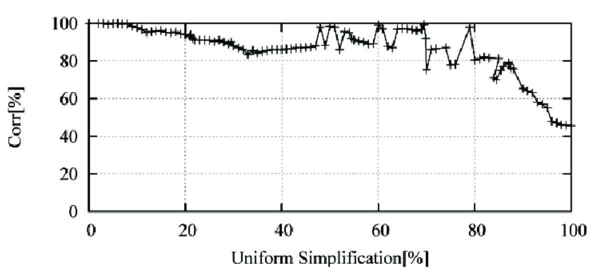


Fig. 16: The robustness experiment of Uniform Simplification (Corr).

From Fig. 18, it can be seen that compared with the algorithms in literature [11] and [12], the robustness

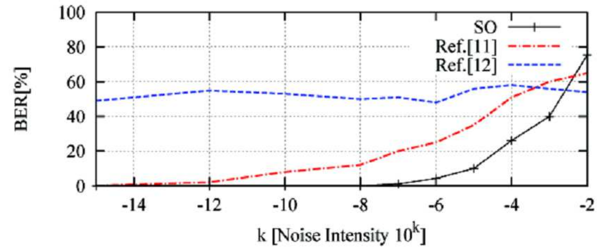


Fig. 17: The robustness comparison between SO and other algorithms (Noise-BER).

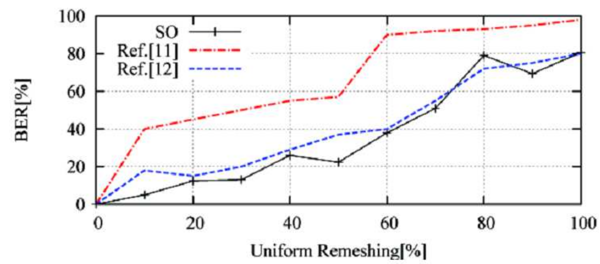


Fig. 18: The robustness comparison between SO and other algorithms (Uniform Re-meshing-BER).

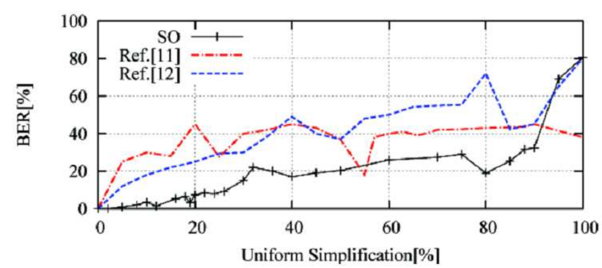


Fig. 19: The robustness comparison between SO and other algorithms (Uniform Simplification-BER).

against re-meshing uniform based on SO algorithm has been greatly improved.

From Fig. 19 it can be seen that compared with the algorithm in literature [11] and [12], the robustness of Uniform Simplification based on SO algorithm has been greatly improved.

3.3 Complexity experiment

As shown in Fig.20, it is the computational complexity contrast experiment between the algorithm based on SO and the algorithm based on MS and SI. It is known that when embedding quantity is same, compared with the algorithm based on MS and SI, the Calculation time of the algorithm based on SO is less.

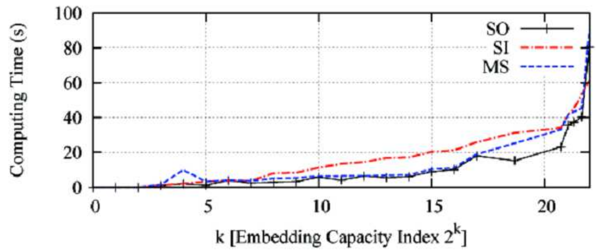


Fig. 20: The complexity experiment comparison among SO, MS and SI (Computing Time-k).

4 Conclusions

Firstly, this algorithm uses longitudinal projection to analyze the profile of 3D model, the profile values on z-axis are analyzed into binary numbers with interval division. Before embedding information, the long, width and height are scaled disproportionately, and the processing embedded region of 3D is fixed. In addition, according to the half of profile, fixed rotated angle and step size, the data can be embedded in redundancy of the whole model and the algorithm can be robust against cutting. Compared with the algorithm of MS and SI, this algorithm has a stronger robustness under similar attack. And compared with the similar algorithm, the complexity of this algorithm is relatively small and it is suitable for the application of high robustness.

Acknowledgments

Our research was funded by several Projects, and the names and numbers of these Projects are as follows: National Natural Science Foundation of China (Grant No. 61402052). National Natural Science Foundation of Tibet (Grant No. 2015ZR-14-20). Natural Science Basic Research Plan in Shaanxi Province of China (Program No. 2014JM2-6105). China Postdoctoral Science Foundation (Grant No. 2015M572510). Shaanxi Province Postdoctoral Science Foundation. The Special Fund for Basic Scientific Research of Central Colleges of Chang'an University (Grant No. 310832151092). National college students' innovative entrepreneurial training fundedation (Grant No. 201510710044).

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