Scalable and High-Precision Function-Approximated Images and Its Secure Coding

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Abstract: - Function-approximated images are suitable for transmission over the networks, because they can be scaled on the sidelines of various resolutions of network terminals with relatively small amount of information. In this work, we use the Fluency function-approximation method that utilizes the Fluency information theory. The theory can deal with images in scalable and high-precision. Transmitted images may contain critical information that must be protected from malicious information tapping. The security, however, depends on the implementations of lower layers of the network protocol stack that are not available in many circumstances. In this paper, we propose a new image description format that applies security to function-approximation coding. It utilizes the structured properties of function-approximation format to enhance its security by hiding the coordinates of components of images. The proposed method is a secure mechanism for image coding itself; therefore, it enables secure transmission of function-approximated images without requiring any secure protocols in the lower layers. Furthermore, being independent from the lower layers, it enables flexible combinations of security mechanisms to enhance the security.

Key-Words: - Function-approximation, Security, Image coding, Fluency information theory.

1 Introduction

Function-approximated images are useful for quality-maintained affine transform, because they consist of a set of drawing information such as coordinates of points, or parameters of lines or surfaces. They can be scaled on the sidelines of various resolutions of network terminals with relatively small amount of information; therefore, they are suitable for transmission over the networks. There are several applications that take this advantage such as the on-demand cartoon publishing system.

Transmitted images may contain critical information that must be protected from malicious information tapping. For example, the publisher of cartoons would not like that the contents are read by the users who have not pay for them. The security, however, depends on the implementations of lower layers of the network protocol stack. In fact, secure protocols are not available in many circumstances. For example, there are several countries that prohibit using encrypted protocols by the law. Even when it is permitted, encryption of images requires much computational cost, so it likely suffers environmental constraints. Digital watermarking is used for protecting digital images and movies; however, this technology is not designed for protecting images from malicious information tapping but designed for protecting images from malicious information alteration.

In this paper, we propose a new image description format that applies security to function-

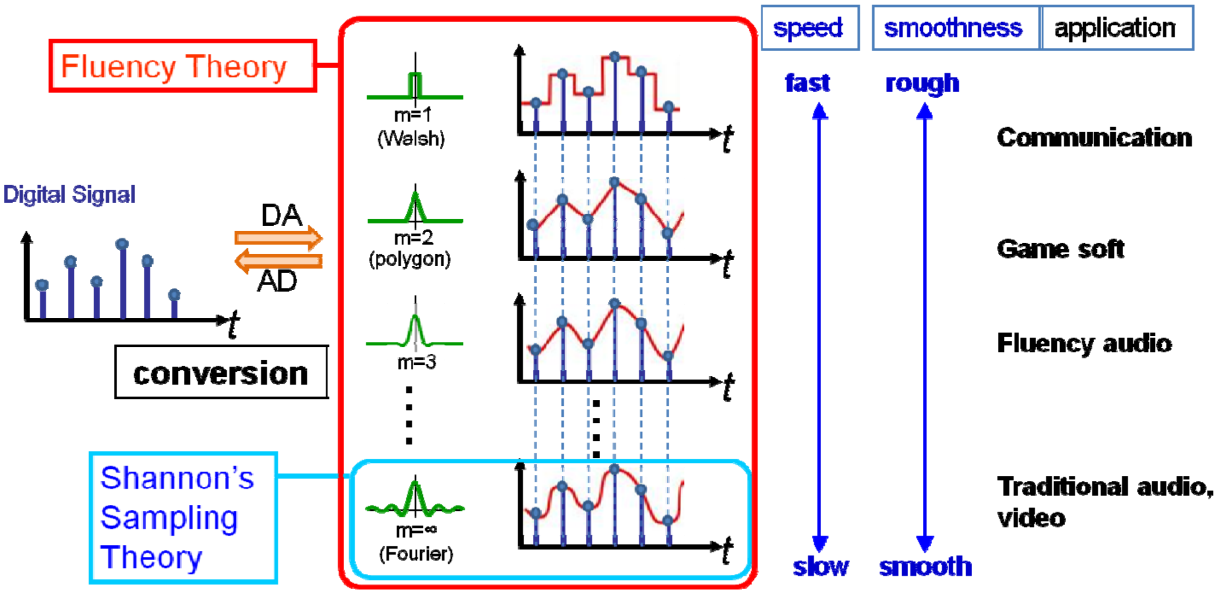

Fig. 1 Overview of the Fluency information theory

approximation coding. It utilizes the structured properties of function-approximation format that is divided into the regional information such as the topology or colors of regions and the layout information such as the coordinates of regions.
Without the layout information, images are not decoded appropriately. Therefore, by hiding the layout information, we can achieve the secure coding for images that allows only pre-assigned users to decode the images.

Our approach is a secure mechanism for image coding itself; all the coding information is coherent for image encoding and decoding. Therefore, it enables secure transmission of function-approximated images without requiring any secure protocols in the lower layers. Furthermore, being independent from the lower layers, it enables flexible combinations of security mechanisms to enhance the security.

This paper is structured as follows. Section 2 explains the function-approximation method used in this work, and pulls out the requirements for secure coding. This work uses the Fluency function-approximation method [1] that utilizes the Fluency information theory [2]. Section 3 illustrates the proposed method by showing the requirements specifications of this method, its encoding process, and its decoding process. Section 4 shows experimental results and discusses the intensity of the proposed method. Section 5 discusses the comparison with conventional methods and extension by combination with other methods. Finally, section 6 concludes this paper.

2 Function-Approximation of Images

Function-approximation is a process that converts raster images to function-approximated images that are sets of drawing information such as coordinates of points, or parameters of lines or surfaces. The following subsection explains one instance of function-approximation: the Fluency function-approximation method [1,3].

2.1 Fluency Information Theory

In multimedia signal processing, interpolation of discrete samples is often used. In Fluency information theory, signal spaces are defined as function spaces composed of piecewise polynomials of degree (m-1) with (m-2) times differentiability. Moreover, the existence of the sampling basis in each space has been proven. For example, when m = 1, the sampling basis is equivalent to the sampling basis in the signal space composed of staircase function, and when m goes to positive infinity, the sampling basis is equivalent to the Shannon's sampling basis which characterizes the band limited signal space. By selecting appropriate signal spaces characterized by parameter m according to the object, the Fluency information theory has already been highly-acclaimed and can be applied in Control [4,5], Filter, Audio, Image Processing etc. Fig. 1 shows the overview of the Fluency information theory.

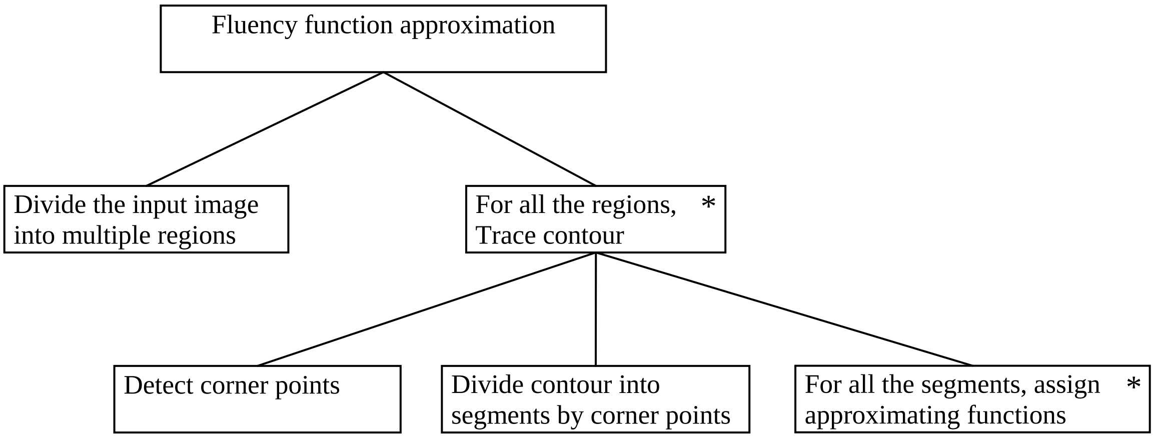

Fig. 2 The Fluency function-approximation

2.2 The Fluency Function-Approximation Method

The JSD diagram [6] in Fig. 2 illustrates the encoding process of Fluency function-approximation. In this diagram, a rectangle represents one process. A rectangle dangling from the upper rectangle represents a subprocess of the upper process. If multiple subprocesses exist, the execution begins from the left-most subprocess, followed by the right neighbor process. The symbol * that appears on the right-upper side of rectangles means the Kleene's closure.

At first, this approximation method divides the input raster image into multiple regions by regarding the contiguous equivalent color of pixels as one region. For all the regions, it then runs the contour tracing algorithm proposed by Sugiyama *et al*. [7]. This is an extension of the chain-code method [8] that enables processing of multicolor images. The traced contours are segmented by corner points [9] and approximated by three types of functions: straight lines (m=2), arcs ($m=\infty$), and quadratic curves (m=3) [10].

Fig. 4 (a) shows a part of cartoon converted from raster format (Fig. 3) into an EPS (Encapsulated PostScript) image by AutoTrace [11], a widely used conventional tool for raster - vector conversion. We can see that the shape of outline becomes unnatural in comparison with the original image. It would appear that poor estimation of control points for Bezier curves causes the situation, not work well. Furthermore, the problem of duplicate tracing common boundaries between regions occurred, adversely affecting the result of function-approximation. For example, overlaps or gaps might appear in the reconstructed image.

Fig. 3 One scene of a cartoon in raster format ((c) Asuka Goto, this scene is taken from "I'm Yatch")

(a) AutoTrace

(b) Fluency

Fig. 4 Contours of the Fluency function-approximated image

Table 1 Comparison of data size

	size(byte)
The original image (BMP)	795430
Fluency approximated image	32725
Fluency approximated image(zipped)	19547
GIF (High Quality)	35783
JPEG (High Quality)	305308

Because no objective evaluation index considering contours currently exists, we have no other choice than a subjective evaluation for function-approximated images. Though we have to evaluate subjective quality statistically in the future, Fig. 4 (b) and Fig. 5 obviously show that the Fluency function-approximation of an image is more accurate in reproduction of the original picture than conventional method. Fig. 6 shows an example of contours of the Fluency function-approximated image.

Table 1 shows comparison of file size between original 256-color bitmap image, fluency function-approximated image and zipped fluency function-approximated image. For the image in Fig. 5, zipped fluency function-approximated image is more compressed than common image compression formats such as JPEG and GIF, so that file size of the function-approximated image is reasonable to be sent over network. However, it is not necessarily appropriate to suggest that file size of function-approximated images are always smaller than that of JPEG or GIF format, because that of function-approximated images generally depend on number of extracted outline segments. For example, as shown by Fig.6, numerous outline segments caused by gradation are extracted from boundary area of left girl's hair in Fig.6. In this case, rest of the image composed of simple elements suitable for function-approximation brings in high compression ratio of whole image. As for display, function-approximated images are adjustable to arbitrary size. Therefore, we can get high-definition display on both a tiny panel of mobile and a large-screen television.

2.3 Requirements for Secure Coding

The aforementioned function-approximation coding method is suitable for quality-maintained affine

Fig. 5 Contours of the Fluency function-approximated image

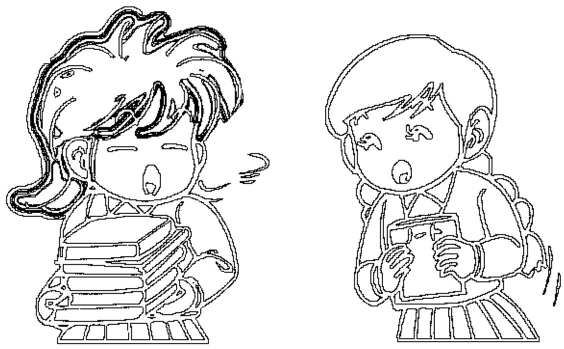

Fig. 6 Contours of the Fluency function-approximated image

transform, because the arbitrary resolutions of images can be reproduced by calculating the pixel values by using the approximating functions. Furthermore, the file size of function-approximated images is relatively small. Therefore, the Fluency function-approximated images are used in several network applications running on various resolutions of digital devices. An on-demand publishing system for cartoons is one example of such applications (Fig. 5). In this system, the Fluency function-approximated cartoons are prepared, and only the pre-registered users can access the contents of cartoons by downloading the viewer specific for the Fluency function-approximated image format. The business process for this system is summarized by Fig. 7.

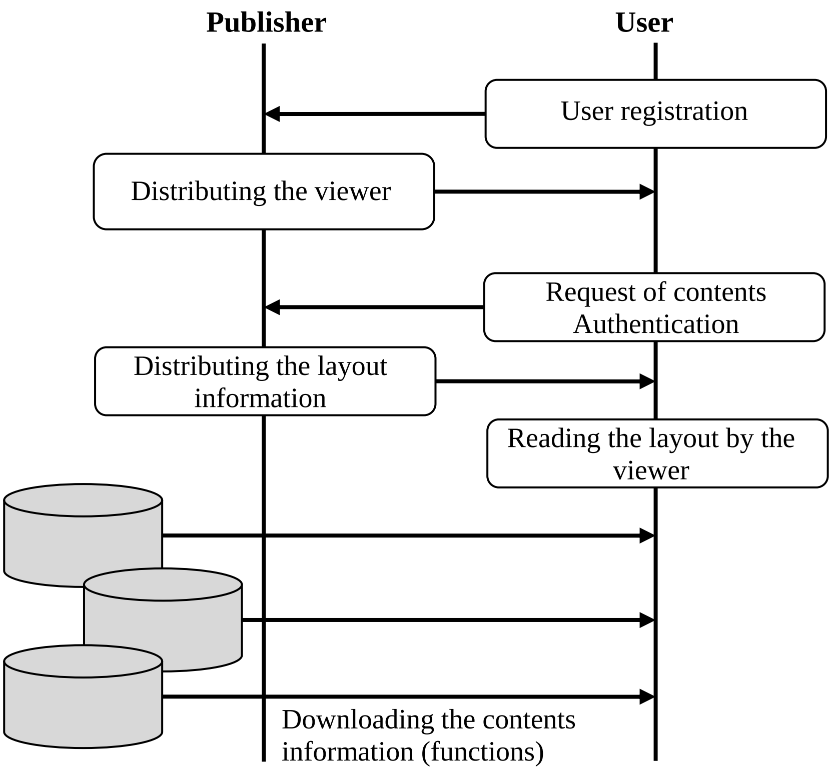

Fig. 7 A business process for the cartoon system.

This adequateness for transmission over the networks triggers the following requirements for the function-approximated images. The transmitted images should be protected from malicious information tapping. For example, the publisher of cartoons would not like that the contents are read by the users who have not pay for them. However, the security depends on the implementations of lower layers of the network protocol stack and secure protocols are actually not available in many circumstances. For example, there are several countries that prohibit using encrypted protocols by the law. Even when it is permitted, encryption of images requires much computational cost, so it likely suffers environmental constraints. Therefore, we should invent a secure coding method for function- approximated images that is independent from the lower secure protocols.

3 The Proposed Method

The function-approximated image format has a structure that appropriately arranges the drawing information. By observing this structure, we pull out the solution for the aforementioned requirements. In this section, we propose the secure coding method for function-approximated images. At first, we set the target (the requirements specifications) of this method; then, we describe the proposed encoding and decoding method.

3.1 Target for The Proposed Method

As stated in the previous section, our proposal is a coding method for function-approximated images.

Furthermore, we concentrate on the compound images that consist of multiple regions, because the information conveyed on images has the form of combinations of multiple regions; *e.g.*, cartoon images consist of multiple scenes; a scene consists of a background, characters, speech balloons, and other objects; a character consists of a face, clothes, and so on. The proposed method is, therefore, a secure coding method for such function-approximated compound images.

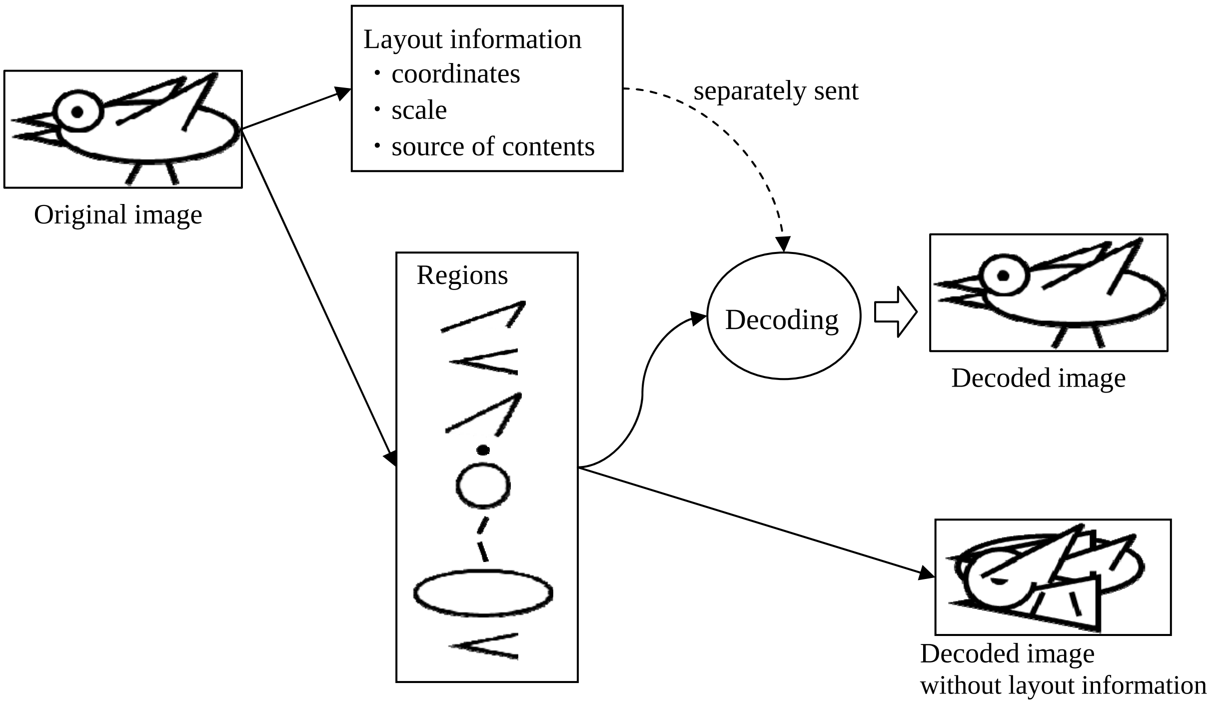

Fig. 8 An overview of the proposed method

3.2 Encoding and Decoding – An Overview

In such a function-approximated compound image, we can see the following structure. At first, an image is described by the multiple function-approximated regions. Then, each region is described by its color, its topology (or shape), and its layout information such as its scale and coordinates that represent where the region is laid out on the image.

The proposed secure coding utilizes this structure (Fig. 8). In the encoding process, the original function-approximated image is divided into the regional information such as the topology or colors of regions, and the layout information such as the coordinates of the regions. In the decoding process, the original image is reproduced by laying out the regions on appropriate place in the image and calculating the pixel values by using the approximating functions and the colors of regions.

To securely send the image over the networks, we can separately send the layout information that is necessary for decoding the image. For example, in the on-demand cartoon publishing system, to allow the pre-registered users to access the cartoon contents, the publisher gives the layout information of the contents to the users. If the publisher can use an encrypted protocol for sending the layout information, she may use it. If she cannot use such a secure protocol for some reasons, she may securely send it in some alternative ways (*e.g.*, by physical mail).

This is a coding method for images, because all the information used in the above process is coherent for image encoding and decoding. However, this is also a security mechanism, because the images are not appropriately reproduced without layout information. This method enables secure transmission of function-approximated images without requiring any secure protocols in the lower layers. Furthermore, being independent from the lower layers, it enables flexible combinations of security mechanisms to enhance the security.

Fig. 9 Result of decoding with layout information.

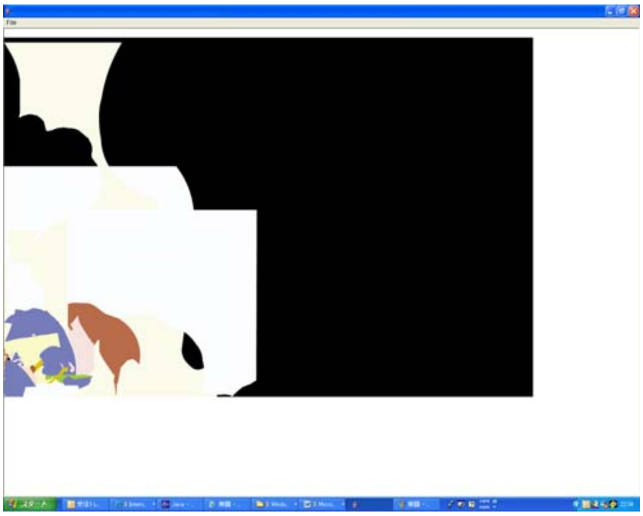

Fig. 10 Result of decoding without layout information.

4 Experimental Results

We show the experimental results of the proposed method using one scene of cartoons shown in Fig. 4. Fig. 9 shows the result of decoding the image with layout information. Fig. 10. shows the result of decoding the image without layout information. This is the result of placing all the regions at the origin.

We can see that the original image is appropriately decoded with layout information, while a meaningless image is decoded without layout information. Without layout information, the processor used for the decoding must predict where each region was placed to reproduce the original image. However, it is almost impossible for computers to recover such a loss of information. Furthermore, the resulting image is so scrambled that it is also very difficult for humans to predict how the original image was formed.

5 Discussion

5.1 Comparison with conventional methods

There are several works for protecting images from malicious tapping.

Akashi *et al.* proposed an encryption method for images using fractal image compression [12]. This method encrypts the input image and divides it into multiple parts by using fractal analysis. By this division, the security is enhanced still further. Our approach may also take the similar approach, by sending the multiple regions separately. The difference is that our approach does not require any encryption mechanisms.

Visual cryptography is an encryption method for images that does not require computations for decryption [13]. This method outputs multiple images from an input image; by printing the output images on transparent sheets and physically superpositioning them, we can reproduce the original image. This method is especially useful for entertainment, but the reproduced image is visually deteriorated.

5.2 Extension by combination with other methods

Our method is successful for function-approximating fonts, illustrations and drawings.

However, this method is only effective for the images that consist of a small number of color regions (we define such images "illustration images"). If this method is applied to more complex images such as photos and gradations, it is difficult to accurately function-approximate them, because a large number of color regions is extracted. Furthermore, a lot of computational time and memory capacity are required. However, by observing the gradation moves its color regularly and continuously, we may find the solution of the problem.

To solve the problem, it is necessary to treat a gradation pattern as one region. Furthermore, it is necessary to correctly reproduce the pixel values from the regions. The conventional method employed in our study approximates only the contours, because the values of pixels in a region is all equivalent. However, if we pursue a more effective region coding, it becomes necessary to devise a way to reproduce the color data of the regions.

Miyamoto et al.[14] have proposed an image segmentation method for function-approximation of gradation images and its description format. In the method, a gradation pattern in the image is recognized as a region by a new labeling method using multiple regression analysis of 2-variable functions. Thus, the problem of the conventional method that a gradation region is divided into numerous small regions is solved. Pixel values in segmented color regions can be reproduced by using the contour and color approximating functions.

The sequence of the method is as follows:

At first, regions that are apparently recognized distinct are segmented in the preprocessing step named "Global Segmentation." This is necessary for enhancing the processing cost. Secondly, colors in regions are approximated by multiple regression analysis of 2-variable functions, planes, spheres, and quadratic surfaces (This process is called Region Approximation). Next, an approximation error is evaluated by calculating the mean square error between the value of approximating functions and the real pixel data. If the error is smaller than the preset threshold, the region segmentation is finished. On the other hand, the process repeats the region segmentation using different 2-variable functions until the approximation error becomes smaller than the threshold.

The experiments show that in this method we can reduce the processing time, and that the file size becomes compact. By evaluating the approximation accuracy with PSNR, it is shown that their approach improves the drawing accuracy.

Fig.11 shows a comparison result of scaling the images using our approach and conventional methods. Table. xx shows a comparison result of the processing cost. It is measured by approximating time, decoding time, the number of contours, and the number of regions. The PSNR (Peak Signal-to-Noise Ratio) measurement is used for evaluating the quality of approximation.

PSNR between the original image X and the processed image X0 is calculated by,

$$\mathrm{PSNR} = \frac{1}{3}\sum_{n=1}^{3} 10\log_{10}\frac{255|X|}{\sum_{p\in X}\{I_n(p) - I_n{}'(p)\}}.$$

The original images in multiple resolutions are prepared, and PSNR evaluation is performed in each resolution. Table.2 shows the result. Finally, the result of file size comparison is shown in Table.3.

The proposed method reduces the number of contours and regions in comparison with the conventional method by recognizing gradation regions.

Table 2 Comparison of data size

Magnification	×1.0	×1.5	×2.0
Conventional method	27.30	21.02	20.46
Proposed method	26.90	21.07	21.30

Table 3 Comparison of data size

File type	File format	Size
Raster image	BMP	430KB
	JPG	19.3KB
Vector image	EPS	3.07KB
	Conventional method	170KB
	Proposed method	3.67KB

The conventional method cannot recognize gradation regions; therefore, numerous small contours are extracted, which makes approximation error visible on the scaled images (Fig.11). On the other hand, the proposed method can recognize gradation regions; therefore, only small number of contours is used for approximation, which enables smooth function approximation. It also reduces the approximating cost and decoding cost. The value of PSNR of the decoded image is improved thus maintaining the drawing accuracy. Furthermore, it is also superior as an image description format, because the file size is compact.

6 Concluding Remarks

In this paper, we propose a new image description format that applies security to function-approximated images. By utilizing the structured nature of function-approximation format, we achieve the secure coding for images that allows only the pre-assigned users to decode the images. The information used for the coding is coherent for image description and reproduction; therefore, this is a coding method for images. At the same time, however, we can also say that this is a security mechanism independent from the lower secure protocol, because the images are not appropriately reproduced without layout information.

In this work, the evaluation for the intensity of the proposed method is subjective. To invent a quantitative measurement for the proposed method to enable an objective evaluation remains for the future work.

(a) Bicubic

(b) B-spline

(c) Fluency (only contours)

(d) Auto Trace

(e) The original EPS

(f) The proposed method

Fig. 11 Comparison of the images scaled to 5 times.

Acknowledgments: We would like to thank Asuka Goto, who is the author of “I’m Yacchi,” the cartoon used in this paper, for graciously granting us permission to reprint the cartoon in this paper. This work was funded by the National Institute of Information and Communications Technology.

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