

A New Scheme for Watermarking Engineering Graph

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Abstract – Engineering graph plays an important role in design and manufacture, such as architecture, machinery, manufacture, military. However, almost no persons consider the security and copyright of two-dimensional engineering graph. A novel method for two-dimensional engineering graph watermark based U system is proposed in this paper. Watermarks generated by this technique can be successfully extracted even after rotation, translation and scaling transform.

Key Words : Watermarking, Engineering graph, U-system, U descriptors

1. Introduction

Digital products can be easily copied and reproduced in a network environment. Therefore, in order to protect digital products' copyright, watermarking techniques have emerged [2]. From early 1990's, watermarking is widely discussed in protection of digital products. As we know, engineering graph plays a very important role in design and manufacture, because it is used to describe designated products by engineers. Engineering graph is the fruits of engineers' hard work, and it is very difficult to be designed. Many people work together day and night to finish a graph. Moreover, an engineering graph embodies many engineers' knowledge and wisdom. So the copyright of engineering graph should be protected.

However, many scientists focus their attentions on applications of watermark in the image, audio, video and text. People have not researched watermarking of two-dimensional engineering except geometric mapping [1] and some watermark of three-dimensional meshes are discussed [7][8][9]. Which is caused by three aspects: (i) Two-dimensional engineering graph have not enough data domain, (ii) there are no less disturbed transformation domain used for embedded watermarking and (iii) two-dimensional engineering graph is easy to be geometrically manipulation.

In 1980's, Qi and Feng presented the U-system and gave the relatively completed theories [3][4][5]. Using these theories, in [10], motivated by in the work in [6], Micchelli and Xu constructed orthogonal multiwavelets for any invariant sets in R^n and later they used the wavelet to develop Galerkin methods and collocation methods to solve integral equations with weakly singular kernels. This indicates the application foreground of U-

system.

The k-degree U-system consists of a series of piecewise k-degree polynomials. It includes not only differentiable functions but also piecewise ones, which include all kinds of discontinuous points on [0,1]. It means that discontinuous points to be in different levels are conducive to express two-dimensional geometric information.

This paper presents a new method for watermarking of two-dimensional engineering graph in U-system. It is organized as follows: the introduction on U system is presented in Section 2; In Section 3, definite the U descriptors and discuss some relative properties; a scheme based on U system for watermarking of two-dimensional engineering graph is described in Section 4 and a robustness of manipulation analysis of the algorithm is performed in section 5; finally, experimental results are presented in Section 6; whereas some conclusions are drawn in Section 7.

2. U-system

In this section, the k-degree U-system is introduced [5].

2.1. Construction of k-degree U-system [3] [4] [5]

Step 1: Taking first $k+1$ polynomials in Legendre orthogonal system, and denote them as, $U_0(x), U_1(x), \dots, U_k(x)$ $x \in [0,1]$.

Step 2: Creating $k+1$ new functions $f_i(x)$, $i=1,2, \dots, k+1$, $x \in [0,1]$ let them satisfy:

(i) $f_i(x)$ is a k-degree piecewise polynomial with the point of division $x=1/2$;

(ii) $\langle f_i(x), f_j(x) \rangle = \delta_{ij}$, $i,j \in \{1,2, \dots, k+1\}$;

(iii) $\langle f_i(x), x^j \rangle = 0$, $i \in \{1,2, \dots, k+1\}$;

(Where $\langle \bullet, \bullet \rangle$ denotes the inner product in the $L_2 [0, 1]$).

Thus, we get the series of functions:

$U_0(x), U_1(x), \dots, U_k(x), f_1(x), f_2(x), \dots, f_{k+1}(x)$;

Step 3: Using "squish-repeat", or say, "direct-copy and opposite-copy" [5], create the other $2 \cdot (k+1)$ functions.

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Beginning from $f_1(x)$, each function generates two new ones as follows,

$$f_{i,1}(x) = \begin{cases} f_i(2x), & 0 < x \leq \frac{1}{2} \\ f_i(2-2x), & \frac{1}{2} < x \leq 1 \end{cases} \quad f_{i,2}(x) = \begin{cases} f_i(2x), & 0 < x \leq \frac{1}{2} \\ -f_i(2-2x), & \frac{1}{2} < x \leq 1 \end{cases}$$

The rest may be deduced by analogy, and we can obtain the class of k-degree U-system.

When $k = 1, 2, 3$, the relative functions are shown in Fig.1. It is noticeable that, in the Fig.1, functions of U-system are denoted as $U_l^{(j)}$, for l denotes the number of fragments and j does the j^{th} function [3].

2.2. Properties of k-degree U-system

K-degree U-System has some properties [3]:

- Orthonormality

$$\langle U_{k,i}(x), U_{k,j}(x) \rangle = \delta_{ij}, \quad i, j = 0, 1, 2, \dots$$

- Convergence of Fourier-U Series by Group

For a given function F, let

$$p_{n+1}F = \sum_{i=0}^n \alpha_i U_{k,i}$$

Then $p_{n+1}F$ is the best L_2 -approximation to F from the space $(U_{k,i})_0^n$. Thus we have

$$\lim_{n \rightarrow \infty} \|F - p_n F\|_2 = 0, \quad F \in L_2[0, 1]$$

$$\lim_{n \rightarrow \infty} \|F - p_{2^n} F\|_{\infty} = 0, \quad F \in C[0, 1]$$

These denote that Fourier-U series have the properties of L_2 -convergence, completeness and convergence uniform by group.

- Fourier-U Series Reproduction

If F is a piecewise k-degree polynomial, which has some discontinuous points on $x = q/2^r$ (q and r are integers), it can be exactly express with limited number of Fourier-U series.

The k-degree U-system has much abundant discon-

tinuity information. Especially using convergence uniform by group and Fourier-U series reproduction, we can embed and extracted watermark for two-dimensional engineering graph.

3. U Descriptors

In this section, we define the U descriptors and discuss some relative properties.

Polygonal curve, which is gotten by sampling, is commonly represented as following:

$z(n) = x(n) + iy(n)$, $n = 0, 1, \dots, N-1$, where $i^2 = -1$. According to the properties of U-system, usually let $N = 2^m$, $m = 0, 1, 2, \dots$. For convenience, we take the 1-degree U-system as example to introduce U descriptors and their properties. For simplicity, U_k is the k^{th} base in 1-degree U-system. The coefficients $\lambda(k)$ of U transformation are called U descriptors trough formula as following:

$$\lambda(k) = \sum_{n=0}^{N-1} z(n) U_k\left(\frac{n}{N-1}\right), \quad 0 \leq n \leq N-1 \quad (1)$$

The above defined U descriptors have the following properties. (See Table 1)

Here, we only give the proof of translation transform. The others are similar.

Theorem1: if $z_1(n) = z(n) + z_0$ then $\lambda_1(k) = \lambda(k) + Nz_0 \delta(k)$,

$$\text{where } \delta(k) = \begin{cases} 0, & k \neq 0 \\ 1, & k = 0 \end{cases}$$

Proof: If $z_1(n) = z(n) + z_0$ then

$$\begin{aligned} \lambda_1(k) &= \sum_{n=0}^{N-1} z(n) U_k\left(\frac{n}{N-1}\right) + \sum_{n=0}^{N-1} z_0 U_k\left(\frac{n}{N-1}\right) \\ &= \lambda(k) + z_0 \sum_{n=0}^{N-1} U_k\left(\frac{n}{N-1}\right) \\ &= \lambda(k) + Nz_0 \delta(k) \end{aligned}$$

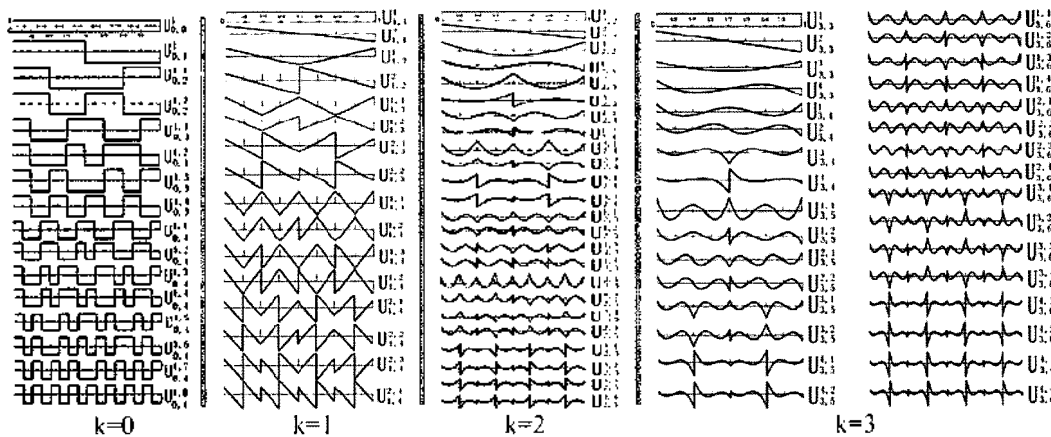


Fig. 1. k-degree U system. (when $k = 0, 1, 2, 3$)

Table 1. Properties of U descriptors.

Geometric Transform	Polygonal Curve	U descriptors
Identical Transform	$z(n)$	$\lambda(k)$
Translation	$z_1(n) = z(n) + z_0$	$\lambda_1(k) = \lambda(k) + Nz_0\delta(k)$, where $\delta(k) = \begin{cases} 0, k \neq 0 \\ 1, k = 0 \end{cases}$
Scale	$z_1(n) = \alpha z(n)$	$\lambda_1(k) = \alpha \lambda(k)$
Rotation	$z_1(n) = z(n) e^{i\theta_0}$	$\lambda_1(k) = \lambda(k) e^{i\theta_0}$

$$\text{so, } \lambda(k) = \lambda(k) + Nz_0\delta(k), \delta(k) = \begin{cases} 0, k \neq 0 \\ 1, k = 0 \end{cases} \quad \square$$

In order to make the U descriptors satisfy the invariance in rotation, translation, scale transform, we can define normalized U descriptors as following:

$$du(k) = \frac{|\lambda(k)|}{|\lambda(1)|}, \quad k = 1, 2, \dots, N-1$$

Next, we prove the invariance in rotation, translation, scale transform.

Theorem 2: Normalized U descriptors are invariant in rotation, translation, scale transform

Proof: Let $z'(n)$ be an engineering graph obtained from $z(n)$: $z'(n)$ translated by z_0 , rotated by θ , and scaled by γ . The corresponding normalized U descriptors of $z'(n)$ is

$$\begin{aligned} \lambda'(k) &= \sum_{n=0}^{N-1} (z(n) + z_0) r e^{i\theta} U_k\left(\frac{n}{N-1}\right), \\ &= \left(\sum_{n=0}^{N-1} (z(n) + z_0) U_k\left(\frac{n}{N-1}\right) \right) r e^{i\theta} \\ &= \left(\sum_{n=0}^{N-1} z(n) U_k\left(\frac{n}{N-1}\right) + \sum_{n=0}^{N-1} z_0 U_k\left(\frac{n}{N-1}\right) \right) r e^{i\theta} \\ &= (\lambda(k) + Nz_0\delta(k)) r e^{i\theta}, \quad \delta(k) = \begin{cases} 0, k \neq 0 \\ 1, k = 0 \end{cases} \end{aligned}$$

So $du'(k) = \frac{|\lambda'(k)|}{|\lambda'(1)|} = \frac{|\lambda(k)|}{|\lambda(1)|} = du(k)$, that is, normalized U descriptors are invariant in rotation, translation, scale transform.

4. Watermark Embedding and Extraction

An engineering graph consists of the geometric and topological information. In [1], geometric information in two-dimensional engineering graph can be described by $V = \{V_1, V_2, V_3, \dots, V_n\}$, where $V_i, i = 1, 2, 3, \dots, n$ are points of the graph, and topological information in two-dimensional graph can be described by $T = \{T_1, T_2, T_3, \dots, T_m\}$, where $T_i, i = 1, 2, 3, \dots, m$ are operations (relationship and properties), such as drawing lines, drawing circles

etc. The two-dimensional engineering graph is $G = V \cup T$.

In fact, each of points V_i represented as a pair of coordinates $x(n), y(n), n = 0, 1, 2, \dots, N-1$. These coordinates can be combined to construct the complex signal $z(n) = x(n) + iy(n), n = 0, 1, 2, \dots, N-1$. Such a signal can be represented by its U descriptors $\lambda(k)$,

$$\lambda(k) = \sum_{n=0}^{N-1} z(n) U_k\left(\frac{n}{N}\right), \quad 0 \leq n \leq N-1,$$

U_k is the k^{th} base of U system. We embed the watermark by changing normalized U descriptors $ud(k)$ using a general superposition law:

$$|du'(k)| = |du(k)| \oplus pW(k), \quad k = 1, \dots, N-1$$

Where P is a factor that determines the power of the watermark. The reason for selecting normalized U descriptors is that the normalized U descriptors are invariant to a number of geometric manipulations. The watermark pattern $W(k)$ is generated using U descriptors of the engineer graph that we have selected, watermark signal $W(k)$ as following:

$$W(k) = du_0(k) \quad k = 1, 2, \dots, N-1.$$

Let $|du'(k)|$ be normalized U descriptors of the watermarked two-dimensional engineering graph. We can extract the watermark as following:

$$W(k) = |du'(k)| - |du(k)|, \quad k = 1, \dots, N-1$$

5. Robustness to Manipulations

Watermark of engineering graph has to face various attacks. In fact, the method is inherently robust to geometrical attack such as translation, rotation, scaling. The robustness results from the properties of the normalized U descriptors $du(k)$.

Translation

Translation of engineering graph affects only the first discrete U system coefficients $\lambda(k), k = 0$. So we obtain watermark immunity to translation by setting $k > 0$.

Rotation

The proposed method is robust to rotation because rotation doesn't affect the magnitude of the engineering

graph's U descriptors.

Scaling

In a scaled two-dimensional engineering graph, the U descriptor magnitude becomes $\gamma|\lambda(k)|$. However, the normalized U descriptors remain invariant because both the numerator and the denominator are multiplied by the same factor γ .

6. Experimental Results

In this section, we make some experiments to support the conclusion of the above analysis. The following is experimental results embedded watermark and extract watermark in a two-dimensional graph.

Experiment 1.

Fig. 1, come from one of AutoCAD2000 sample files, is an original two-dimensional graph. Fig. 2 is an engineering graph with watermark. Fig. 3 is an initial watermark graph and Fig. 4 is the watermark graph extracted from fig. 2.

Experiment 2.

We get Figs. 5, 6 through rotating Fig 2 by $\pi/2$ and π . Fig. 7 is the watermark graph extracted from fig. 5 and Fig. 8 is the watermark graph extracted from fig. 6.

Experiment 3.

Fig. 9 is the result of scaling fig. 2 by double. Fig. 10 is the watermark graph extracted from figure 9.

7. Conclusions and Future Work

In this paper, a new scheme for watermarking of two-dimensional engineering graph is proposed by using U system. And the validity of the algorithm is demonstrated by the experiments. The experimental results

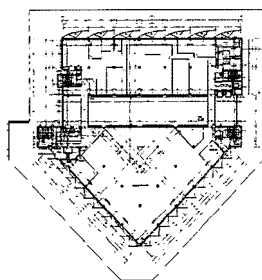


Fig. 1. original two-dimensional graph.

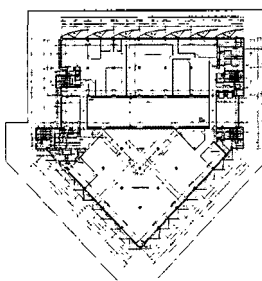


Fig. 2. engineering graph with watermark.



Fig. 3. Initial watermark graph.



Fig. 4. watermark graph extracted from.

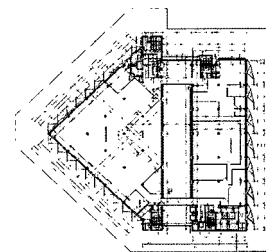


Fig. 5. rotated by $\pi/2$.

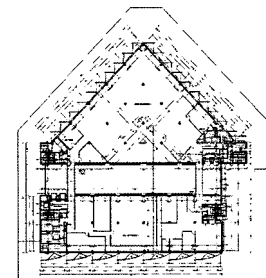


Fig. 6. rotated by π .



Fig. 7. watermark graph extracted from fig.5.



Fig. 8. watermark graph extracted from fig. 6.

show that the goal that using U system to watermark of two-dimensional engineering graph is achieved.

The contribution of this work to the previous work on using so called "U system" in watermarking of two-dimensional engineering graph. It's a different idea to

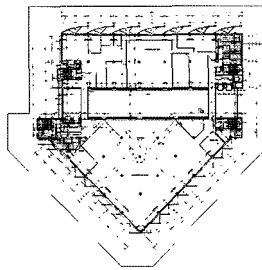


Fig. 9. scaled by double.



Fig. 10. watermark graph extracted from fig. 9.

other similar schemes.

The future work will focus on following:

- 1) Discovering the laws of engineering graph and improving our methods to resist more strong attacks.
- 2) Using the algorithm in wider type of sample data to justify its validity.
- 3) Finding some new approaches to protect the copyright and security of engineering graph.

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