速報論文
48A - 4 - 17

2D 인테그라-노말라이저를 이용한 2D 영상간의 거리 측정방법

Distance Measure for Images Using 2D Integra-Normalizer

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Abstract - In this paper, a new method of measuring of distance between digital images, the 2D Integra-Normalizer, is proposed and compared with the grey block distance (GBD) to show its superiority in measuring the visual similarity of images. The 2D Integra-Normalizer removes a restriction that the image to be compared is 2^n dimension where n is a positive integer, which means that any dimensional image can be applied to the 2D Integra-Normalizer for measuring distance of images. In addition, the 2D Integra-Normalizer measures the distance of images more in detail than the GBD with a better interpretation that is more close to human's intuitive understanding.

Key Words : 2D Integra-Normalizer, Similarity measurement, Image classification.

1. Introduction

In general, the difference between two-dimensional images is obtained by a metric that can measure the distance between images with measuring the degree of similarity. The choice of a metric for measuring similarity between images is so important that it may determine the performance of classification. In general, the Least Square Error(LSE) is used for measuring a distance between 2D images. However, there are some cases that the results of classification do not agree with human's understanding when the LSE is used [1, 2, 3, 4, 5].

Recently, many different approaches are studied in order to measure the distance between one dimensional signals and between two dimensional images. For instance, in order to overcome the limitation of standard objective measures of distances between images, the comparison of images ar full resolution, an alternative approach, the grey block distance(GBD), was proposed [1] where images are compared at different resolutions.

The 2D Integra-Normalizer is a paradigm that is able to interpret the relation between two dimensional images, especially the degree of image similarity not only for information separation but also for measuring distance closely to human's intuitive understanding. The images which the Integra-Normalizer can be applied to include both continuous and discontinuous images.

In this paper, a new method of measuring image distance, the 2D Integra-Normalizer is presented, whose property is superior to the GBD in a sense that the interpretation of the relation between images is more close to human's intuitive understanding and that the measurement of the degree of similarity between images is more effective than GBD.

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接受日子 : 1998年 12月 3日
最終完了 : 1999年 3月 8日

2. Integra-Normalizer for 2-D Image Comparison

Without loss of generality, let X be a space of two-dimensional real-valued functions of bounded variation, defined in the unit area $I\times I$ where $I=[0,1]\subset R$.

Definition 1 [Bounded Variation]
A 2D function is said to be of bounded variation on $I\times I$ is finite if its total variation $Var(w)$ of a function w on $I\times I$ is finite, where

$$Var(w)=sup\sum_{i=1}^{m}\sum_{j=1}^{n}|w(t_{i,j})-w(t_{i,j-1})|.$$

The supre- mum being taken over all partitions of
$0.0=t_{i,0}<t_{i,1}<\cdots<t_{i,n}=1.0,$
$0.0=t_{0,j}<t_{1,j}<\cdots<t_{j,m}=1.0,$ of $I\times I$,
where i,j are integers and $n,m\in N$ are arbitrary. Let

a distance between two images I, I' in X be demoted as $E_{lse}(I,I')=\sum_{I\times I}(I(i,j)-I'(i,j))^2$ for digital images and $E_{lse}(I,I')=\int_{I\times I}(I(i,j)-I'(i,j))^2$ for continuous images, which is known as the Least Square Error(LSE), that is the metric in l^2 space. There are some cases that the LSE method does not interpret the restriction on the LSE, a linear operator defined as the 2D Integra-Normalizer is proposed.

Definition: [2D Integra-Normalizer] With $f(x,y)$ as an integrable 2D function over the unit area $I\times I$, a monotonically increasing 2D function can be generated by an n-times integration over $I\times I$ with $0.0\le f(x,y)\le 1.0$. Let $0.0\le g(x,y)\le 1.0$ be an integrable functions with variable x and y in the unit area $I\times I$. Let Φ^n be an n-times integration with respect to two variables x and y, and Γ^n be the quotient Φ^n over $Max(\Phi^n)$, so that, for $n=k$, $f^k=\Gamma^n(f)$ and $g^k=\Gamma(g)$ become continuous monotonically increasing 2D functions. Let's define Γ^n as the 2D Integra-Normalizer.

Lemma 1 Let $I\times I$ be the area $[0,1]\times[0,1]$ in R^2 and $f(x,y)\in X$ where X is a real-valued 2D function of a bounded variation. Then for $f(x,y)\ge 0$ for all $x,y\in I\times I$, $\int_0^{x+\delta}\int_0^{y+\varepsilon} f(s,t)\,dsdt \ge \int_0^x\int_0^y f(s,t)\,dsdt$, where $(x,y)\in I\times I$ and $\varepsilon,\ \delta\ge 0$, such that $F(x,y)=\int_0^x\int_0^y f(s,t)\,dsdt$ is a monotonically increasing 2D function.

Proof is trivial.

Lemma2 The 2D Integra-Normalizer forces the 2D function to have the most of 2D function's energy be near to the point (1.0, 1.0) in $I\times I$. As the degree of 2D Integra-Normalizer increases to ∞, all functions defined in X become an impulse-like whose area is equal to 1.0, such as

$$\Gamma^{\infty}f(x,y)=\begin{cases}1.0-\varepsilon, & \text{if } x,y\in[1.0,\ 1.0],\\ \varepsilon, & (x,y)\in([0,\ 1),[0,\ 1)).\end{cases}$$

Proof: Since the function f(x, y) in $I\times I$ *is a positive 2D function,* $f^k(x,y)$ *is a monotonic increasing function where* $f(x,y)\in X$ *and* f^k *is the image that obtained using the kth 2D Integra-Normalizer. From the facts that* $Max(f^k(x,y))=f^k(1.0,1.0)=1.0$ *and the slope of* $f^k(1.0+0^-,\ 1.0+0^-)\ge f^{k-1}(1.0+0^-,\ 1.0+0^-)$, *as* $k\to\infty$, *The slope of* $f^k(1.0+0^-,\ 1.0+0^-)$ *goes to* ∞. *Also, with the fact that* $f^k(x,y)\le f^k(x+\varepsilon,y+\varepsilon)$ *where* ε *is a small number,* $f^k(t)$ *becomes an impulse-like signal that has most of its weight at (1.0, 1.0).*

Lemma 3: [Usage of a Pilot Block] When the compared functions are the flat top blocks that have the same support in $I\times I$ with different magnitude. The waveforms from the 2D Integra-Normalizer are the same due to the normalization process. This is avoided by employing a block as a pilot block at the same location for all compared images.

Proof: Let f, g are the flat top blocks, which have a flat top, with a support $[a,b]\times[a,b]\subseteq I\times I$. *Then*

$$\Gamma(f(x,y))=\frac{\int_a^y\int_a^x f(\tau,\gamma)d\tau d\gamma}{S}$$ *is equal to*

$$\Gamma(g(x,y))=\frac{\int_a^y\int_a^x g(\tau,\gamma)d\tau d\gamma}{T}$$, *for all*

$(x,y)\in[a,b]\times[a,b]$ *where* $S=\int_a^b\int_a^b f(\tau,\gamma)d\tau d\gamma$, $T=\int_a^b\int_a^b g(\tau,\gamma)d\tau d\gamma$. *For instance,* $\Gamma(f(a,\ a))=\Gamma(g(a,\ a))=0.0$, $\Gamma(f(b,\ b))=\Gamma(g(b,\ b))=1.0$, *and the slopes of both* $\Gamma(f(x,\ y))$, $\Gamma(g(x,\ y))$ *are the same.*

This can be avoid by employing a pilot block in $I\times I$ *whose support is not in* $[a,b]\times[a,b]$. *If the volume of the pilot block is* A, *then* $\Gamma(f(x,\ y))=\Gamma(g(x,\ y))$ *does not hold where* $(x,y)\in[a,b]\times[a,b]$. *For instance, at a point (b, b),* $\frac{A}{A+S}$ *is not equal to* $\frac{A}{A+T}$ *since* $S\neq T$.

Theorem If the images to be compared are bounded 2D functions, the relative similarity between the waveforms can be obtained using the Integra-Normalizer with the pilot pulse.

The relative similarity between images is measured by $Similarity=e^{-E_{lse}(f^k,g^k)}$ for the images $f,\ g\in X$, such that the relative similarity can be mapped into $[0,\ 1]\subset R$. One of the good properties of the 2D Integra-Normalizer is that it interprets the relation between images closely to human's intuitive understanding.

3. Comparison Between 2-D Integra-Normalizer and GND

Given two-dimensional (2-D) discrete digital images I and I', the grey block distance [1] is defined as $G(I, I') = \sum_{1}^{N} d_i$ where $d_i = \frac{1}{2^r}\frac{1}{2^{2r-2}}\sum_{j=1}^{2^{r-1}}\sum_{i=1}^{i=2^{r-1}} |g_{i,j} - g'_{i,j}|$, and 2^{r-1} is the number of rectangles on the image where resolution $r \in N$ where N is the number of resolutions with the average grey level $g_{i,j}$ and $g'_{i,j}$ of each rectangle in I and I'. However, there are some cases that the GBD does not work properly in measuring distance. The followings are some of the counter examples where the GBD does not work.

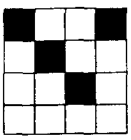

Fig.1: Image 1

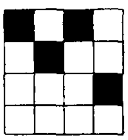

Fig. 2: Image 2

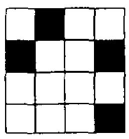

Fig. 3: Image 3

Relations between Figure 1, 2 and 3 are simple counter examples where the GBD and the LSE do not separate three images, but the Intega-Normalizer does as shown in Table 1. Using the GBD, for r = 1 and 2, the average greyness of each block is the same for the three images such that the distances d_1, and d_2 are all zeros. For $r \geq 3$, the corresponding blocks on the three images always have one block white and the other black. Thus G(Figure 1, Figure 2) = G(Figure 2, Figure 3) = $\frac{1}{16}$, such that Figure 1, 3 cannot be separated with respect to Figure 2 due to the same distance.

Table 1: Comparison Between Distance Measurement Methods

Compared Figures	Least Square Error	GBD Distance	Integra-Normalizer
Figure 1 and 2	2.8284	1/16	0.8825
Figure 2 and 3	2.8284	1/16	0.8395
Figure 1 and 3	2.0	1/32	0.9512

The GBD is superior to the LSE method by possessing the multi-resolution property similarly to the Haar wavelets. Though, a defect of GBD is that it groups patterns into a category, which classifies a group of elements roughly that does not quite agree human's intuition. However, the Integra-Normalizer separates Figures 1, 3 with respect to Figure 2, which is superior to the GBD and the LSE methods for measuring distance of 2-D images. In addition to this, the Integra-Normalizer interprets the relation between images more closely to the human's intuitive understanding.

The intuitive interpretation of relation between images by the integra-Normalizer is demonstrated using the nine images, from Figure 4 to 8 and image 12. The image 12 in Table 2 is an image that is the 90 degree rotated of Figure 4.

As the results shown in Table 2, the similarity obtained presents the degree of similarity between images, that quite agree with human's intuitive understanding. The LSE cannot separate the eight images, Figure 4, 5, 6, 7, 8, 9, 10, 11, each of which has only one pixel difference from Figure 4 where the LSE is 1,4142. One of the cases that the GBD shows difference to the Integra-Normalizer is the distance between Figure 4 and Figure 9, 10, 11 where the GBD becomes 0.0088 for each of the comparison while the Integra-Normalizer provides separation as shown in Table 2.

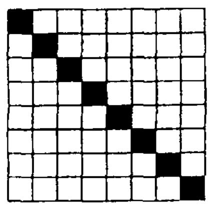

Figure 4: Image 4

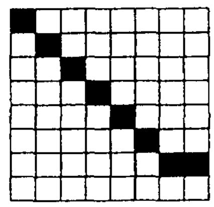

Figure 5: Image 5

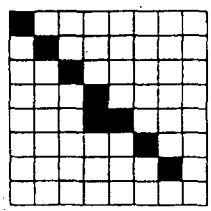

Figure 6: Image 6

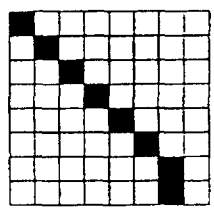

Figure 7: Image 7

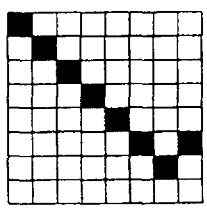

Figure 8: Image 8

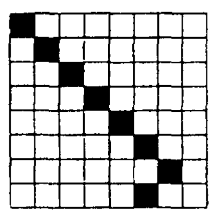

Figure 9: Image 9

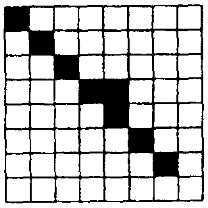

Figure 10: Image 10

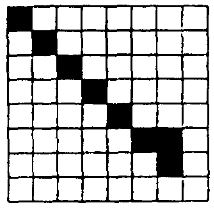

Figure 11: Image 11

Table 2: Distance Measurement Using Integra-Normalizer for 2-D

Images	Image 4	Image 5	Image 6	Image 7	Image 8	Image 9	Image 10	Image 11	Image 12
Image 4	1.0000	0.9876	0.9876	0.9876	0.7886	0.9753	0.9394	0.9753	0.3499
Image 5	0.9876	1.0000	0.9753	0.7985	0.7985	0.9876	0.9512	0.9632	0.3456
Image 6	0.9876	0.9753	1.0000	0.7985	0.7965	0.9632	0.9512	0.9876	0.3456
Image 7	0.7886	0.7985	0.7985	1.0000	0.9048	0.8086	0.8395	0.8086	0.2760
Image 8	0.7886	0.7985	0.7965	0.9048	1.0000	0.8086	0.8395	0.8086	0.2760
Image 9	0.9753	0.9876	0.9632	0.8086	0.8086	1.0000	0.9632	0.9512	0.3413
Image 10	0.9384	0.9512	0.9512	0.8395	0.8395	0.9632	1.0000	0.9394	0.3287
Image 11	0.9753	0.9632	0.9876	0.8086	0.8086	0.9512	0.9394	1.0000	0.3413
Image 12	0.3499	0.3456	0.3456	0.2760	0.2760	0.3413	0.3287	0.3413	1.0000

4. Conclusion

In this paper, a new method of measuring distance between images is proposed. A new scheme, the Integra-Normalizer for 2-dimensional signal, is more effective than GBD in measuring the degree of similarity by partitioning a group of images more in detail. In addition to this, the Integra-Normalizer separates images more similarity to human's intuition than the GBD and the LSE. The analytical results were shown to agree well with simulation results.

References

[1] Phillip Juffs, Edwin Beggs, and Farzin Deravi, "A Multiresolution Distance Measure for Images," IEEE Signal Processing Letters, Vol. 5, No.6, June 1998.

[2] Sung-Soo Kim, Takis Kasparis, "A Modified Domain Deformation Theory for 1-D Signal Classification," IEEE Signal Processing Letters, Vol. 5. No. 5, May 1998.

[3] Mohamad. A. Akra, Sanjoy K. Mitter,"Waveform Recognition in the Presence of Domain and Amplitude Noise," IEEE Trans. on Information Theory, Vol. 43, No. 1, January 1997.

[4] M. A. Akra, "Automated text recognition," Ph.D. dissertation, MIT, Cambridge, MA, 1993.

[5] Sung-Soo Kim, "3-D Object Recognition Using Open-Ball Scheme via Wavelets and Domain Deformation Theory," Ph.D. dissertation, University of Central Florida, 1997.

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