Image Database Retrieval by Fast Hermite Projection Method

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Abstract

In this paper we will consider a new scheme of image database retrieval by fast Hermite projection method. The database contained 4100 images. The method is based on an expansion into series of eigenfunctions of the Fourier transform. Photo normalization includes following steps of preprocessing: resampling, corners detection, rotation, perspective and parallelogram elimination, painting cutting, ranging and color plane elimination. The searching is based on the database query by fast Hermite coefficients and retrieving from the database nearest record by quadratic discrepancy.

Keywords: *Fourier transform, Hermite functions, fast Hermite projection method, image processing, photo parameterization, image database retrieval.*

1. INTRODUCTION

The emergence of multimedia, the availability of large digital archives, and the rapid growth of the World Wide Web (WWW) have recently attracted research efforts in providing tools for effective retrieval of image data based on their content (content-based image retrieval). The relevance of content based image retrieval for many applications, ranging from art galleries and museum archives to pictures and photographs, medical and geographic databases, criminal investigations, intellectual properties and trademarks, and fashion and interior design, make this research field one of the fastest growing in information technology [1], [2], [3]. The aim of the work is painting based image database retrieval by fast Hermite projection method.

The proposed method is based on the features of Hermite functions and properties of paintings (for testing purpose two digital cameras at 2+ Mp were used). An expansion of signal information into a series of these functions enables us to perform information analysis of the signal and its Fourier transform at the same time, because the Hermite functions are the eigenfunctions of Fourier transform. These functions are widely used in image processing [4], [5], [6] and streaming waveform data processing [7], [8]. It is also necessary to underline that the joint localization of Hermite functions in the both frequency and space domains makes using these functions very stable to information errors.

This work illustrates some possibilities to take full advantage of the use of this method.

2. 2D HERMITE FUNCTIONS

The 2D Hermite functions are localized in frequency and space domains, stable to information errors and form a full orthonormal in $L_2(-\infty,\infty)\times(-\infty,\infty)$ system of functions.

The 2D Hermite functions are defined as:

$$\psi_{nm}(x,y)=\frac{(-1)^{n+m}e^{x^2/2+y^2/2}}{\sqrt{2^{n+m}\,n!\,m!\,\pi}}\cdot\frac{d^n(e^{-x^2})}{dx^n}\cdot\frac{d^m(e^{-y^2})}{dy^m}.$$

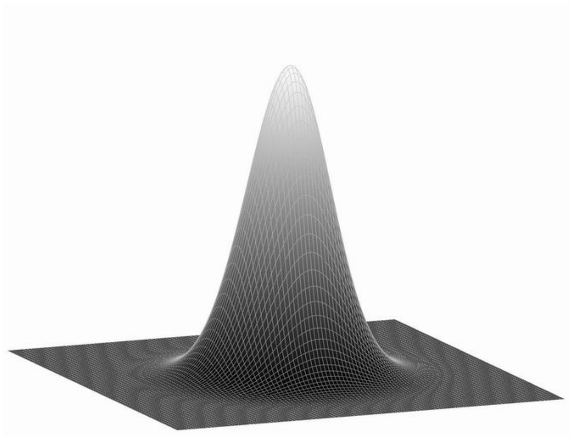
They also can be determined by superposition of the 1D recurrent formulae [4].

Moreover the 2D Hermite functions are the eigenfunctions of the Fourier transform:

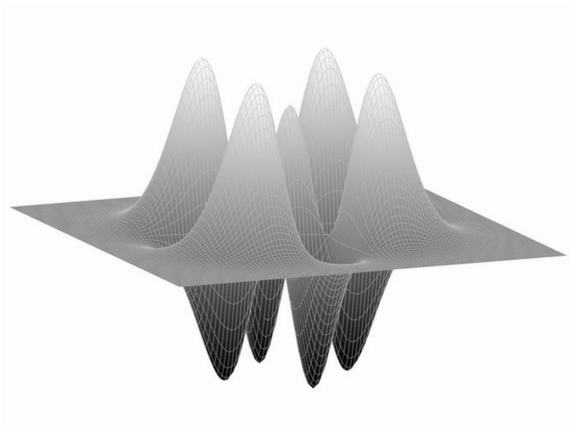
$$F(\psi_{nm})=i^{n+m}\psi_{nm},$$

where F denotes Fourier transform operator.

The graphs of the 2D Hermite functions are depicted in figure 1.



$\psi_{0,0}(x,y)$



$\psi_{2,2}(x,y)$

Figure 1: 2D Hermite functions

3. PROBLEM STATEMENT AND PHOTO LIMITATIONS

A problem of artistic image retrieval was considered. The images were considered as real photos of paintings with their frames.

The following limitations were imposed:

- Photo type: 1600x1200x24b or 1200x1600x24b or higher quality.
- There must be part of a painting in the center of a photo.
- There must be only one object (painting) on a photo.
- A painting must be completely inside on a photo.
- Maximal photocamera turning from vertical axis – 26 degree.
- A photo must be nonblurry.
- Minimal distance from a painting to the border of a photo – 8 pixels.
- A painting must be on monotone absorbent background with color for easy detecting border of a painting.
- A painting must be rectangular.
- A painting must have uniform illumination.
- A flash on photocamera must be off.

4. IMAGE DATABASE RETRIEVAL

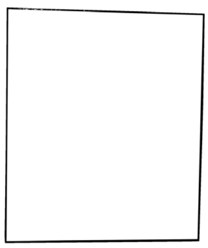
General scheme of the preprocessing algorithm for image database retrieval is depicted in figure 2.

Incoming image

Digital photo, properties: 1600x1200x24bit (1200x1600x24bit) or higher.	

V

Image normalization

Resampling and corners detection.	
Turning, perspective and parallelogram elimination.	
Painting cutting, ranging and color plane elimination.	

V

Fast Hermite parameterization

Difference, obtained after fast Hermite parameterization of 512x512x24bit image by 32x32x3 coefficients.	
Restored image by Hermite coefficients.	

Figure 2: Preprocessing algorithm

At stage of fast Hermite parameterization, at first, we should select the number of the Hermite functions used for photo parameterization. The optimal number for current task is 32x32x3 functions (1024 coefficients per each color channel). Further we stretch our approximation's photo $[-A_0, A_0]\times[-A_0, A_0]$ to the area $[-A_{1x}, A_{1x}]\times[-A_{1y}, A_{1y}]$, defined from the next criteria:

$$A_{1x} = \arg_x\left(\max_{x,y}\left(\psi_{31,31}(x,y)\right)\right),$$

$$A_{1y} = \arg_y\left(\max_{x,y}\left(\psi_{31,31}(x,y)\right)\right).$$

Then we decompose image function $f(x,y)$ into Fourier series by Hermite functions:

$$I(x,y) = \sum_{i=0}^{31}\sum_{j=0}^{31} c_{ij}\,\psi_{ij}(x,y),$$

$$c_{ij} = \int_{-A_{1x}}^{A_{1x}}\int_{-A_{1y}}^{A_{1y}} f(x,y)\,\psi_{ij}(x,y)\,dxdy.$$

It can be represented as superposition of 1D Hermite projection methods:

$$I(x,y) = \sum_{j=0}^{32} \overline{\overline{c_j}}\, \psi_j(y),$$

$$\overline{\overline{c_j}}(x) = \int_{-A_{1y}}^{A_{1y}} \overline{f}(x,\xi)\, \psi_j(\xi)\, d\xi,$$

$$\overline{f}(x,\xi) = \sum_{i=0}^{32} \overline{c_i}(\xi)\, \psi_i(x),$$

$$\overline{c_i}(\xi) = \int_{-A_{1x}}^{A_{1x}} f(\chi,\xi)\, \psi_i(\chi)\, d\chi.$$

The integrals can be approximated by Gauss-Hermite quadrature [9]:

$$c_n \approx \frac{1}{N} \sum_{m=1}^{N} \mu_{N-1}^{n}(x_m)\, f(x_m),$$

where

$\mu_{N-1}^{n}(x_m)$ is array of constants:

$$\mu_{N-1}^{n}(x_m) = \frac{\psi_n(x_m)}{\psi_{N-1}{}^{2}(x_m)}.$$

We used averaged values in mesh points calculated by averaging values in ε_m-vicinity of point x_m instead of $f(x_m)$ to increase quality and stability of coding. The ε_m-vicinities were calculated by following conditions: an intersection of any two ε_m-vicinities for different m must be void, an aggregation of all ε_m-vicinities must be equal a domain of array.

Error range of applying Gauss-Hermite quadrature can be calculated by formula [10]:

$$R(f) = \frac{N!\sqrt{\pi}}{2^N (2N)!} \cdot \frac{d^{2N}}{dx^{2N}} \left(f(x)\, e^{x^2/2} \right) \Bigg|_{x=\eta}.$$

Since the Hermite functions are the eigenfunctions of Fourier transform, we have also found Fourier transform of the approximation for our photo.

The next step after image preprocessing is executing database query by fast Hermite coefficients and retrieving from the database nearest record by quadratic discrepancy.

All calculations pass in automatic mode and don't require person interruption.

For acquiring statistics two digital photocameras were used – Nikon ColorPix 950 and Sony DSC-V1 – for taking 80 photos of 68 paintings. The number of photos (64 base photos) has been enhanced 4 times by special low-detecting differing algorithm, 8 times by inverting color channels, 2 times by mirroring. Other 12 photos were used for testing proposed algorithm. So, 4100 photos were obtained for database and 12 photos – for testing purpose.

During the test, compressed (JPEG) and uncompressed (TIFF) photos were used and authors didn't obtain any incorrect result. Presented algorithm has been also tested with Hermite projection method and discrete Fourier transform. Obtained results for Fourier transform show also very good results, but it has been detected, that proposed algorithm, based on fast Hermite projection method, is more stable for external noise. More detailed results are depicted below (they are sorted by discrepancy in L2):

	Average discrepancy (FHPM)	Average discrepancy (HPM)	Average discrepancy (DFT)
1	0,00842	0.00859	0.00376
2	0,02179	0.02193	0.00955
3	0,04076	0.04149	0.01786
4	0,04995	0.05080	0.02199
5	0,12151	0.12583	0.05358
10	0,13737	0.14170	0.06051
50	0,16554	0.16941	0.07291
100	0,17022	0.17400	0.07480
500	0,18527	0.18888	0.08147
1000	0,20081	0.20421	0.08804
2000	0,22143	0.22444	0.09677
3000	0,24527	0.24811	0.10668
4000	0,31266	0.31408	0.13477
4100	0,38318	0.39052	0.16732

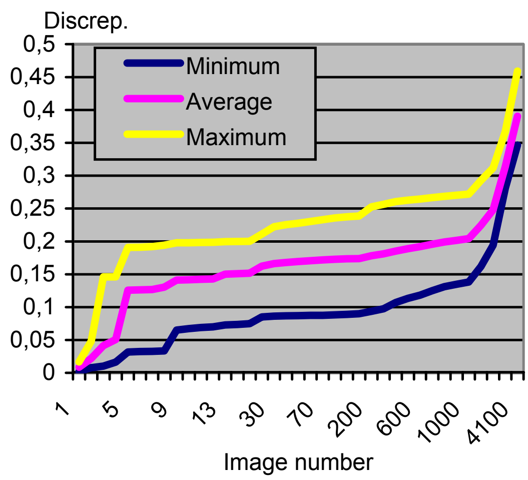


Figure 3: Hermite discrepancy

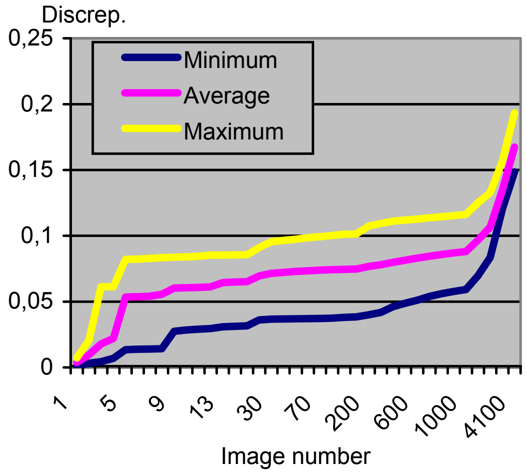


Figure 4: Fourier discrepancy

All calculations were realized on Pentium-M 1500 MHz under OS MS Windows XP Professional. For generation additional 4032 images (36Gb, 9.0Mb per image) were spent 3 hour 59 minutes of processing time. After that 4100 images were processed and added to database. The testing was based on unused images. Searching time was on average 3-7 seconds (server), parameterization with preprocessing time was on average 4-6 seconds (client, 2-3 Mp), but only 0.045 seconds were spent for fast Hermite parameterization (the time for standard Hermite parameterization was about 0.5 seconds).

5. CONCLUSION

In this paper we considered image database retrieval by fast Hermite projection method, which shows 11x acceleration comparing with standard Hermite projection method for parameterization stage of considered task of image database retrieval. We used an expansion into series of numerically localized eigenfunctions of the Fourier transform that enabled us to use advantages of a time-frequency analysis and have accelerated it by Gauss-Hermite quadrature. Also we have used preprocessing (normalization) stage for elimination rotation, perspective, parallelogram, shifts, background and illumination.

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