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VIETNAM ACADEMY OF SIENCE AND TECHNOLOGY

GRADUATE UNIVERSITY OF SIENCE AND TECHNOLOGY

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SOME TECHNIQUES TO IMPROVE THE EFFICIENCY OF IMAGE RESEARCH BY CONTENT BASED ON ADAPTIVE DISTANCE MEASUREMENT AND SPECTRUM CLASSIFICATION

Major: Computer science
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SUMMARY OF COMPUTER DOCTORAL THESIS

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The thesis has been completed at: Graduate University of Science and Technology- Vietnam Academy of Science and Technology

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The thesis shall be defended in front of the Thesis Committee at Vietnam Academy Of Science And Technology - Graduate University Of Science And Technology, at …..… hour……, date…… month…..…year 2023

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- The National Library of Vietnam
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HEADING

1. The urgency of the thesis

Over the past decade, we have seen a steady growth in the number of digital photos taken, stored and shared every day. The estimated number of digital photos taken in 2021 is more than 5 trillion. About 85% of them were taken with mobile phones. A large part of them are available on the Internet through websites, photo galleries (Flickr and Shutterstock), and various social media Facebook, Instagram.... The majority of photo databases This, is not sorted nor does it have metadata and tags attached. In addition, image databases are popular in application fields such as crime prevention, medicine, architecture, remote sensing, etc. Increasingly developed image acquisition and storage techniques have allowed the construction Huge photo databases. Content-based image retrieval (CBIR) solves the problem of image library management, image classification, object recognition in images, online image lookup and many other applications related to image processing and vision. computer sense. Therefore, quickly and accurately looking up a desired image in a large and diverse digital image database is an extremely difficult and challenging task in the field of computer vision today.

1. Objectives of the thesis

General goal of the thesis:

Proposed image search method to improve search accuracy.

Specific goals of the thesis:

- Improving the image retrieval method using the ODLDA method by finding an optimal distance measure, which reduces the distance between pairs of images with high similarity and maximizes the distance between pairs of images with low similarity.

- Proposing an image retrieval method based on graph cut theory, without having to calculate the Laplacian matrix, eigenvalues and eigenvectors.

2. Research object

The research object of the thesis is content-based image retrieval by combining optimal distance and linear discriminant analysis, conducting experiments on the Corel image database (10,800 images), Graph

partitioning with SIMPLIcity image database (1,000 images with 10 topics. Each image has dimensions of 256×384 or 384×256).

3. Research method of the thesis

Phương pháp nghiên cứu của luận án là nghiên cứu lý thuyết và nghiên cứu thực nghiệm. Về nghiên cứu lý thuyết: giới thiệu về tra cứu ảnh dựa vào nội dung, một số nghiên cứu ảnh dựa vào nội dung, trích rút đặc trưng, thông tin không gian, đo khoảng cách, phân cụm, giảm khoảng cách ngữ nghĩa, phân tích phân biệt tuyến tính, đánh giá hiệu năng.

4. Layout of the thesis

This thesis is arranged into three chapters:

Chapter 1: Overview of content-based image retrieval.

Chapter 2: Improving the efficiency of content-based image retrieval by combining distance optimization and linear discriminant analysis.

Chapter 3: Improving the efficiency of content-based image retrieval using graph partitioning

Finally, the thesis provides some conclusions and future research directions.

5. Results and novelty of the thesis

(1) Contributing to the research direction, the thesis makes the following contributions:

(2) (1) The thesis improves image retrieval accuracy through building a feature vector database with the deep learning network CNN AlextNet.

(3) (2) In the process of learning similarity measures, the thesis considers both related and unrelated sets and uses the LDA linear discriminant analysis learning method to adjust the weight function of the distance function. .

(4) (3) Proposing an efficient image retrieval method using a graph clustering (MGC) that fully exploits similarity information of image sets. Experimental results of the thesis on a feature database of 1,000 images have shown that the proposed method MGC provides a higher accuracy than other methods..

Chapter 1. OVERVIEW OF CONTENT-BASED IMAGE RESEARCH

This chapter provides a basic introduction to content-based image retrieval, including: reviewing the development of content-based image retrieval techniques, how to describe visual content, and measuring the distance between visual content. relationships, indexing schemes, query generation, associated feedback mechanisms. Besides, this chapter also presents system performance evaluation. Finally, this chapter provides some conclusions and directions for research.

1.1. Introduce

Content-based image retrieval (CBIR), uses an image's visual content such as color, shape, texture, and spatial layout to represent and index images. In typical CBIR systems (Figure I.1),

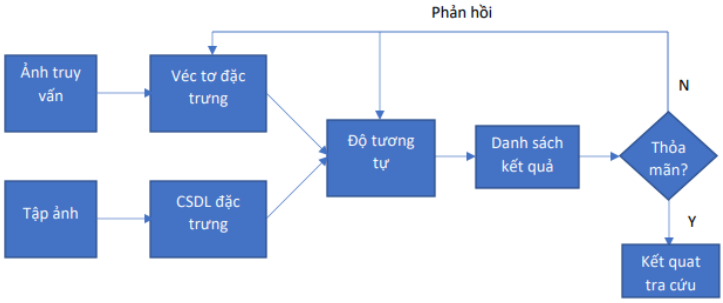

Figure I.1. Content-based image retrieval scheme

1.2. Description of image content

In general, image content can include the visual content of the image and the semantic content of the image. Visual content can be very general or domain specific. General image content includes color, texture, shape, and spatial relationships,..... Color

1.2.1. Color space

RGB space is a widely used color space for displaying images. It consists of three components: red, green and blue.

1.2.2. Color moment

Color moments have been used successfully in image retrieval systems [1,2] (such as QBIC), especially when images contain only objects.

First-order (mean), second-order (variance) and third-order (skewness) color moments have been proven to be effective and efficient in representing the color distribution of an image.

1.2.3. Color chart

A color histogram is an efficient representation of the color content of an image if the color is unique from the rest of the data set.

1.2.4. Correlation color chart

The color correlogram was proposed to describe not only the color distribution of pixels, but also the spatial correlation of color pairs. The first and second dimensions of a three-dimensional histogram are the color of any pair of pixels, and the third dimension is their spatial distance.

1.2.5. Color characteristics

The color not only reflects the surface material but also changes significantly with changes in illumination, surface orientation, and camera viewing geometry. This variability must be taken into account. However, invariance to these environmental factors is not considered in most of the colors introduced above.

1.2.6. Structural characteristics.

1.2.7. Features Tamura

Tamura includes roughness, contrast, directionality, evenness, and roughness, designed in accordance with psychological studies on human perception of texture. Tamura's first three components were used in several well-known early image retrieval systems, such as QBIC and Photobook.

1.2.8. Roughness

Coarseness is a measure of the detail of a texture.

1.2.9. Contrast

1.2.10. Simultaneous autoregressive model

1.2.11. Gabor filter

Gabor filters have been widely used to extract image features, especially texture features. [26].

1.2.12. Wavelet transform

1.2.13. Shape characteristics

1.2.14. Immutable moment

The invariant moment called ‘invariant moment’ is a set of numerical characteristics of an image calculated based on the intensity values of pixels

in the image. The purpose of using invariant moments is to create features whose properties do not change when the image is changed by geometric transformations such as rotation, enlargement, reduction or symmetric flipping, which helps for object recognition and classification to become more stable in different situations.

1.2.15. Rotation

Rotation angle represents the degree of rotation of the image around a corresponding axis. In two-dimensional space, rotation is measured in degrees and is usually clockwise. In image processing, to transform rotation, geometric transformations such as rotation matrices are often used. The rotation matrix is 2x2 and the rotation angle is calculated in radians. The rotation matrix applies to the pixels in the image to perform the rotation transformation. Rotation transform used in creating rotated versions of images to create more diverse training data in machine learning models.

1.2.16. Fourier description

The Fourier variable is a good tool in image processing that helps analyze and process image signals based on their frequency spectrum.

1.2.17. 1.2.17. Calculate periodicity, eccentricity and principal axis direction

Periodicity is calculated as:

$$\alpha = \frac{4\pi S}{P^2} \tag{1.20}$$

Where, S is the size and P is the circumference of an object. This value corresponds to a perfect circle.

The principal axis direction can be defined as the direction of the largest eigensign of the second-order covariance matrix of a region or an object. Eccentricity can be defined as the ratio between the smallest eigenvalue and the largest eigenvalue.

For content-based image lookup, user interaction with the lookup system is important because it can dynamically modify queries by involving the user in the lookup process. The user interface in the image retrieval system includes query creation and results presentation.

Semantic distance is one of the typical examples in content-based image retrieval. Semantic distance is distance that refers to the degree of similarity or similarity (distance) between human perception and the understanding derived from computer algorithms of the same image. This distance has a direct impact on the evaluation of images as similar by algorithms. Image similarity is determined by an observer in a specific context at a high semantic level.

With today's large image data and the amount of images increasing hour by hour and day by day, researching effective CBIR methods is extremely necessary. And for the CBIR system, increasing image retrieval accuracy and increasing image retrieval speed are the first and necessary two

things to do. To do these two things, the CBIR system must focus on the two most important stages: feature extraction and similarity calculation.

Chapter 2: IMPROVE THE EFFICIENCY OF CONTENT-BASED IMAGE RESEARCH BY COMBINATION OF OPTIMAL DISTANCE AND LINEAR DISCRIMINANT ANALYSIS

Content-based image retrieval is performed by comparing the similarity between the query image representation and each image representation in the database. Therefore, image representation and similarity measure are two core parts of content-based image retrieval. In image retrieval with associated feedback, distance computation and classification have a large influence on image retrieval accuracy. In this chapter, the thesis presents the proposed image retrieval method, called ODLDA (Image Retrieval using the optimal distance and linear discriminant analysis). The proposed method can exploit user feedback from a set of related and unrelated images, which uses linear discriminant analysis to find a linear projection with an improved similarity measure. Experimental results performed on two standard data sets have shown the progress of the proposed method. The proposed method can effectively exploit user feedback from sets of unrelated images, using linear discriminant analysis to find a linear projection with an improved similarity measure.

2.1. Introduce

In a typical CBIR system, low-level visual features include color, texture, and shape, which are automatically extracted and represented as feature vectors.

The idea of learning a similarity measure is to find an optimal distance measure that minimizes the distance between pairs of similar images and maximizes the distance between pairs of dissimilar images. This optimal distance measure is then used to reclassify the entire image set and return better results. In the thesis, the PhD student proposed an effective image retrieval technique (ODLDA). The proposed method is more accurate than some existing methods because the feature representation is more semantic and the learned similarity measures are better suited to the data. Through

experiments with two standard databases, the accuracy of the proposed method is shown.

2.2. Related research

Learning similarity measures in content-based image retrieval has received attention from the research community. In image retrieval with associated feedback, the input data of similarity measure learning algorithms is often divided into two groups: the first group consists of similar image pairs; and the second group includes similar image pairs and dissimilar image pairs.

In the MCML method.

The idea of the LMNN method.

Ideas in Xing's method.

The idea of the RCA method.

From the limited analysis of the above related studies, the thesis proposes an improved image retrieval method. Improved distance function based on maximizing the ratio between the total distance of dissimilar image pairs and the total distance of similar image pairs. Here, researchers consider both sets of similar and dissimilar images to find the weight matrix and the exact process of image retrieval.

2.3. Proposed image reclassification method

In this section, the thesis briefly presents the proposed method. First, the method proposes the construction of deep features to represent images. Next, on the result set of the initial lookup phase that uses deep features, the user marks the images related to the query image to obtain the response image set. This resulting response set includes images related and unrelated to the query image. Based on the relevant image set, the proposed method trains the model to find the linear projection. This linear projection satisfies the condition that the variance between samples in the same related set is minimized while the variance between related samples and unrelated samples is maximized. Besides, the proposed method also builds a Mahalanobis similarity measure by finding the optimal matrix M in the improved similarity measure formula.

2.3.1. Diagram of the proposed method

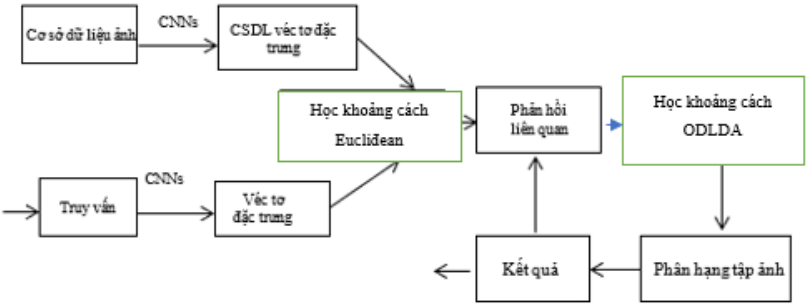

Figure II. 1. Diagram of the proposed ODLDA method

2.3.2. Image retrieval using deep learning

In recent years, CNN networks have shown good results in the field of computer vision such as image classification, object recognition, and semantic segmentation. On that basis, there have been studies on image retrieval based on content using CNN and have obtained positive results.

Suppose NCS has two images in database I_1 and I_2, deep features are extracted using CNN model pre-trained on ImageNet dataset. The deep features of two images I_1 and I_2 are represented by x_1 and x_2. The similarity measure used to compare these two features is L_2:

$$L_2\_Similarity(x_i, x_j) = \|x_i - x_j\|_2 = \sqrt{(x_i - x_j)^T (x_i - x_j)} \quad (2.1)$$

Formula (2.1) indicates the similarity between images I_i and I_j, the similarity value is larger for images I_i and I_j that are more similar.

The similarity measure uses approach 2) to compare two image feature vectors calculated by the formulaL_T:

$$LT\_similarity(x_i, x_j) = \|x_i - x_j\|_T$$

$$= \sqrt{(x_i - x_j)^T T(x_i - x_j)} \qquad (2.2)$$

With a matrix, obtained from learning the similarity index that satisfies the condition of being a positive definite matrix, because the similarity index must be positive and the similarity index has the smallest value when

$$x_i = x_j$$

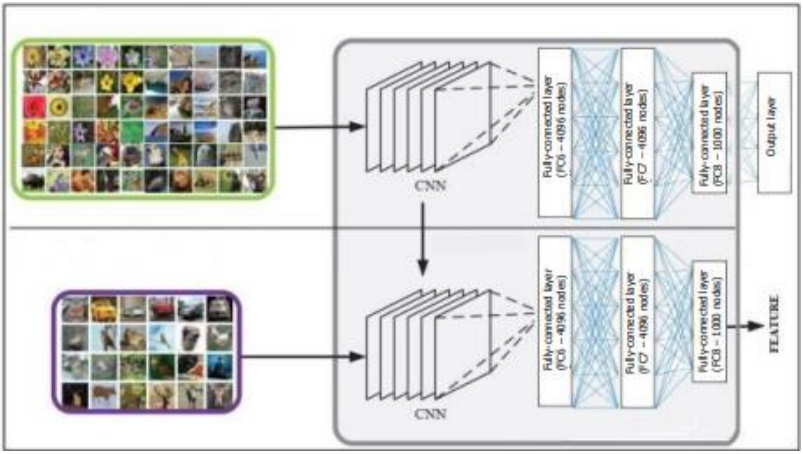

Figure II. 2. Representation learning architecture based on pre-trained CNN model.

2.4. Improved distance measurement.

2.5. Image lookup algorithm

Algorithm 1.1, called ODLDA, is an image retrieval algorithm based on linear discriminant analysis and optimal distance.

Algorithm1.1.ODLDA

Input:

Image set : ***DB***

Initialization query image: **Q**

Returned image number for each iteration : ***N***

Output:

Result: ***R***

1. S ←IRL<DB,*M*>;
2. S_q ←IRL<Q,*M*>;
3. $Result_{initial}(Q)$←**$Retrieval_{Initial}$**(Sq,S,N)
4. R← $Result_{initial}(Q)$;
5. **Repeat**

5.1.< $F_{feature}$, F^{+}_{label}, F^{-}_{label}>**)←Feedback** (R); *relevantfeedback*

5.2. ***W*** **= LDA(**$F_{feature}$**,** F^{+}_{label}, F^{-}_{label}**);** *Find the optimal transformation* **W**

5.3. $W_o = W^T W$; The *optimal weight of the Mahalanobis distance function*

5.4. *R*← ***Ranking*** *(S,Wo,N); Rerank the set of images according to the Mahalanobis distance function with the optimal weight.*

Until (User stops responding);

$\boldsymbol{Kmeans(f)}$

6**. Return** R ;

.

2.6. Experimental results

2.6.1. Experimental environment

1) Corel image data set:

2) Ground truth set for evaluating the accuracy of CBIR: the ground truth set is used to evaluate the accuracy of the CBIR system, i.e., the relevant and irrelevant images are known previously in this background trust file. Accordingly, the image retrieval system considers images that are related to the query image as images with the same topic. This set contains three columns (heading: Query Image ID, Image ID, and Relation) and contains 1,981,320 rows.

3) SIMPLIcity image set: To demonstrate the performance of the proposed method.

Figure II. 3. Some samples in the Corel photo library.

Figure II. 4. Some samples in the SIMPLIcity set.

2.6.2. Experimental evaluation

The average accuracy of the methods is shown in Table II.1. In this table, the thesis finds that the method using the original Euclidean distance measure has the lowest accuracy. The three methods Xing, RCA, and MCML have similar accuracy. The proposed method has the highest accuracy.

Phương pháp	**Độ chính xác trung trình theo các phạm vi (scope)**		
	50	**100**	**150**

Euclide	0.2887	0.3065	0.3199
Euclide cải tiến (Improved Euclidean)	0.3135	0.42658	0.4846
Xing	0.3324	0.47658	0.5125
RCA	0.3424	0.48058	0.5015
MCML	0.3328	0.47958	0.4925
ODLDA	**0.4836**	**0.5065**	**0.5199**

Table II. 1. Compare the average accuracy of methods at scope 50, 100 and 150 on Corel data set.

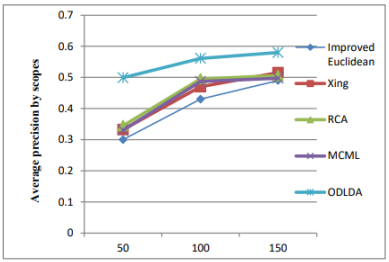

Figure II. 5. Compare the average accuracy of the methods on scopes 50, 100 and 150 on the SIMPLIcity set.

2.7. Conclusion of chapter 2

The thesis presents the ODLDA method, an effective image retrieval technique that improves the performance of multi-point image retrieval systems. ODLDA effectively exploits user information through relevant and unrelated sample sets, performs optimal projection learning to separate irrelevant images and narrow the gap of related images. The proposed method finds the optimal weight matrix of the Mahalanobis distance function and uses this improved distance function to rank the entire database image set and return the result set to the user. Experimental results on two databases

demonstrated that ODLDA provides much higher accuracy than the improved Euclid, Euclid, RCA and OASIS methods.

Experimental results on a feature database of 1000 images have shown that the proposed method provides a much higher accuracy than other methods.

Part of the research at CT4.

Chapter 3. IMPROVING THE EFFICIENCY OF CONTENT-BASED IMAGE RESEARCH USING GRAPH SEGMENTATION

In recent years, many image retrieval (CBIR) methods follow a related feedback approach designed to bridge the semantic gap between low-level visual features and high-level semantic concepts. for image retrieval tasks. However, current image retrieval methods only care about the similarity between the query image and the database image and do not pay attention to the similarity between images in the target image set. In this thesis, the PhD student proposes an efficient image retrieval method using a graph clustering (MGC) that fully exploits similarity information of image sets. The above experimental section provides experimental results to demonstrate the accuracy of the proposed method.

3.1. Improve the efficiency of image retrieval based on content using graph partitioning

3.1.1. Introduce

In image processing, graphs and graph partitions are important concepts used to describe and analyze image characteristics to improve content-based image retrieval.

3.1.2. Related research:

3.1.3. Proposed method:

The MGC method is described by the diagram in Figure III.1.

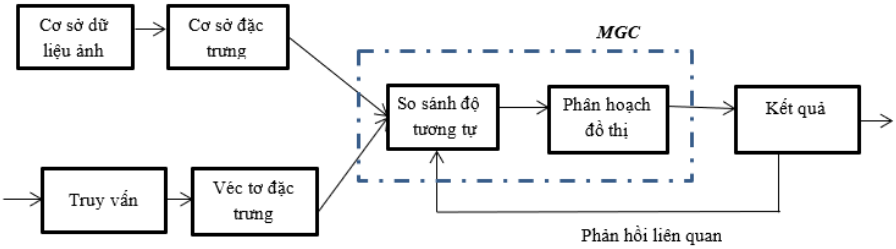

Figure III. 1. Diagram of image retrieval using graph partitioning

3.1.4. Iterative minimum cut clustering

The Iterative Min Cut Clustering (IMC) method is proposed to divide the same data set X = {x_1,...,x_N} ⊂ R^H into C clusters by minimizing the objective function:

$\sum_{i,j} w_{ij}$, x_i và x_j belong to different clusters

(3.1)

where w_ij is the similarity (edge weight) between x_i and x_j. For convenient calculation, we normalize the data points x_i (i ϵ {1,...,N}) as follows:

$$x_i = \frac{x_i}{max\{x_i[1],\dots,x_N[H]\}}$$

(3.2)

The similarity w_ij is calculated by:

$$w_{ij} = \begin{cases} exp(-\frac{||x_i - x_j||^2}{2\sigma^2}), & x_i \text{ và } x_j \; are \; neighbors \\ 0 \; if \; vice \; versa \end{cases}$$

–(3.3)

To solve problem (1), we define a feature q (a scalar quantity) for each data point. If two data points belong to the same cluster, their q will have the same value and vice versa. There q_i represents the feature of x_i, q_i=q_j if x_i and x_j belong to the same cluster and q_i≠q_j otherwise.

Vector $q = [q_i] = [q_1, \dots, q_N]^T$ can be viewed as an assigned dimension of the data set X. (1) is equivalent to:

$$Q = \sum_{i=1}^{N} \sum_{j=1}^{N} w_{ij} (q_i - q_j)^2 \quad (3.4)$$

Based on the relationship between (4) and the Laplacian matrix:

$$q^T L q = \frac{1}{2} \sum_{i,j} w_{ij} (q_i - q_j)^2 \quad (3.5)$$

To solve problems ***(3.4)***:

$$\frac{\partial Q}{\partial q_i} = 2 \sum_j (q_i - q_j) w_{ij} - 2j \sum_j (q_i - q_j) w_{ji} = 4 \sum_j (q_i - q_j) w_{ij} \quad (3.6)$$

$$\frac{\partial Q}{\partial q_i} = 0 \Rightarrow q_i = \frac{\sum_j w_{ij} q_i}{\sum_j w_{ij}} \quad (3.7)$$

According to the variational method, f contains 2 values of f, which can be considered as f^k và f^{k+1}.

Once we have the feature vector f, we partition the vector f into C clusters using some basic algorithms such as K-means or using the threshold method as follows.:

$$L_i = \begin{cases} 0 \ nếu \ f_i < T_1 \\ \dots \\ c \ nếu \ T_c < f_i < T_{c+1} \\ \dots \\ C \ nếu \ f_i > T_C \end{cases}$$

With T_c being the cth threshold.

From there, we have the IMC algorithm to solve problem (3.4) as follows:

Thuật toán phân cụm IMC

Input: X

Output: c cụm: T_1, T_2,…,T_C

Tính w_{ij} theo công thức (3.3), random initialization for

Lặp:

Tính f^{n+1} với $f_i^{(n+1)} = \frac{\sum_j w_{ij} f_j^{(n)}}{\sum_j w_{ij}}$

Cho đến khi $|f^{(n)} - f^{(n+1)}|$ is less than a specified tolerance or n has reached the maximum number of iterations.
Return $T_1, T_2, \ldots, T_C$

Lookup algorithm

Algorithm 1.3 below describes an efficient image retrieval algorithm using graph partitioning (An efficient image retrieval method using a graph clustering-MGC)

Algorithm 1.3. Image lookup algorithm *MGC*

Input:
Collection of photos: ***S***
Query photo: $\boldsymbol{Q_{initial}}$
Number of images returned at each iteration: N

Output:
List of summary results: $\boldsymbol{Result(Q_{merger})}$

1. Result($Q_{initial}$) ←< q, *d*, *S*, *N*>;
3. **IMC** (Result($Q_{initial}$,N), C, X)
5. **Repeat**
   5.1 **for** i=1 to C do
   Result(Q_{merger}) ← <{$q^{(1)}$, $q^{(2)}$,..., $q^{(c)}$}, *d*, *S*, *N*>;
   5.3 Relevant(Q_{merger},M)←***Feedback***(Result(Q_{merger}), N');
   until (User stop responding);
6. **Return** Result(Q_{merger});

3.2. Experiment

3.2.1. Experimental environment

To determine the effectiveness of the proposed models and methods, experiments were built on the dotNET platform, C#, Python and Matlab programming languages. Computer configuration used for experimentation: Intel(R) Core(TM) i7-8550U CPU @ 1.80GHz, DDRam - 16GB and Windows 11 Professional operating system.

Experiments are described in two forms: graphs and tables; In which, the lookup performance in terms of accuracy and range is described by graphs,

tables describe the average evaluation index and comparison between methods.

SIMPLIcity experimental image database

Figure III. 2. Some photos in SIMPLIcity

3.2.2. Perform queries and evaluations

In the experimental part, the parameters are selected as follows:

The search efficiency is evaluated on the SIMPLIcity image database of 1000 images, all images in the database are used to perform queries.

Compare the average accuracy of the proposed method Five different methods include CRF, ERF and MGC.

.

Phương pháp	**Trung bình độ chính xác**		
	2	**4**	**6**
CRF	0.4388	0.5065	0.5199

ERF	0.5138	0.62658	0.6846
MGC	**0.658**	**0.68658**	**0.7825**

Table III. 1. Table of average accuracy results of 3 methods according to the number of query points in three responses.

In Table III.1. shows the average accuracy of three methods, CRF, ERF, and the proposed method MGC at levels of 2, 4, and 6 query points, with the proposed method the number of query points determined by the number of clusters. With 2 query points, the accuracy of the proposed method is 12.92%, 21.92% higher than the two CRF and ERF methods. In case of 4 query points, the accuracy of the proposed method CRF and ERF is 12.00%, 6%. In case of 8 query points, the proposed method has higher accuracy than CRF and ERF by 16.47%, 26.26% respectively.

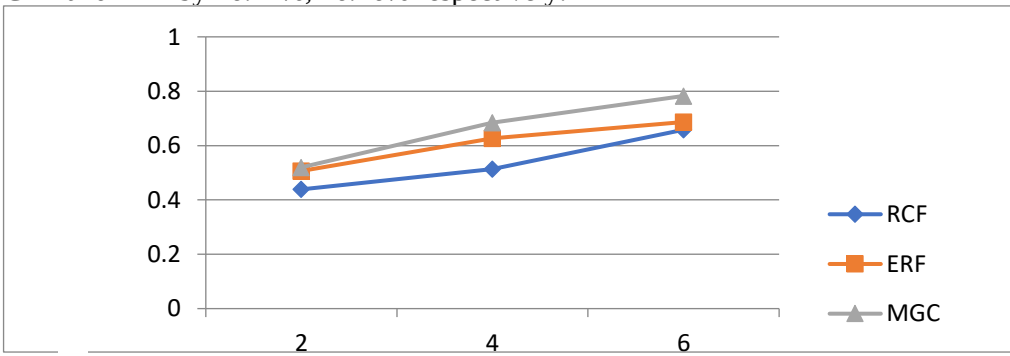

Figure III. 3. Compare the accuracy of three methods on SIMPLIcity image collection

Conclusion of chapter 3

In addition, the PhD student has focused on proposing a method, called An efficient image retrieval method using a graph clustering (MGC) that fully exploits the degree information. Similar to the image set. Experimental results of graduate students on the image feature database have

shown that the proposed method MGC provides a much higher accuracy than other methods.

CONCLUSION AND DEVELOPMENT DIRECTIONS

The thesis presents the ODLDA method, an effective image retrieval technique that improves the performance of multi-point image retrieval systems. ODLDA effectively exploits user information through relevant and unrelated sample sets, performs optimal projection learning to separate irrelevant images and narrow the gap of related images. The proposed method finds the optimal weight matrix of the Mahalanobis distance function and uses this improved distance function to rank the entire database image set and return the result set to the user. Experimental results on two databases demonstrated that ODLDA provides much higher accuracy than the improved Euclid, Euclid, RCA and OASIS methods.

In addition, the PhD student has focused on proposing a method, called An efficient image retrieval method using a graph clustering (MGC) that fully exploits the degree information. Similar to the image set. Experimental results of graduate students on the image feature database have shown that the proposed method MGC provides a much higher accuracy than other methods.

In summary, the thesis has achieved the following results:

The first is: Improve the image retrieval method by finding an optimal distance measure, which reduces the distance between pairs of images with high similarity and maximizes the distance between pairs of images with low similarity. .

Second is: Proposing an image retrieval method based on graph cutting theory, without having to calculate the Laplacian matrix, eigenvalues and eigenvectors.

However, the thesis still has some limitations: the solution method in the thesis has only been evaluated on a medium database but not on large databases.

From the above limitations, the next research direction of the thesis is: integration with deep learning models to adapt to large databases and increase accuracy.

LIST OF PUBLICATIONS

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