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# Research Outline and Progress of Digital Protection on Thangka

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## 1. Introduction

“Thangka”, is a transliteration of Tibetan which means painted scroll, an art of painting on silk or cloth. It is primary components of painting art in the snow-capped plateau with clear characteristics of Tibetan art, and has a long history, in the early 7th century when the Tubo dynasty had emerged, Buddhism are introduced Tibet. Extant the earliest Thangka is 11th century works, the most Thangka works are 17th century and 18th century, and all works that stored generation before the 15th century with little. Its content interesting and colorful stories, relate to religion, the history event, personage, local conditions and customs, folklore, fairy story, building layout, astronomy calendar, Tibetan medicine, Tibetan pharmacology and so on. It is extremely costful image data and historical material in Tibetan Studies field, and regarded as an encyclopedia of the history and society of the Tibetan ethnic group, having highly studying value and aesthetic value. The digital protection of Thangka is a very meaningful work with rapid development in information technology age. Thangka is the use of powder and drawn by the exquisite natural pigment paintings, and Thangka image different from the natural landscape images and other images due to its wide range of themes, the wide variety, different sorts, abstruse semantic, plump picture, brilliant color. So its research relate to image processing, pattern recognition, computer vision, artificial intelligence, etc.

Since 2002, our group relative research of Thangka image has been the State Ethnic Affairs Commission of China, the National Natural Science Foundation of China, Gansu Province Natural Science Foundation funding. So far, all aspects of research had made some progress, there are also many issues to be studied in further. Our study aim in the cultural heritage of Thangka is digital protection, main content include inpainting of Thangka image, construction of resource repository and information retrieval of Thangka, some research results will be introduced in this chapter.

The rest is organized as follows: Section 2 introduce restoration of Thangka image. Construction of recourse repository of Thangka is expressed in section 3. Thangka image annotation and retrieval semantic-based is introduced in section 4. In section 5, content-based Thangka image retrieval is introduced. Finally, the conclusions are drawn in section 6.

## 2. Restoration of Thangka image

### 2.1 Damaged Thangka and the meaning of digital restoration

Image inpainting is not only an important research topic in the fields of image restoration but also a research hotspot in image processing and computer vision. It's main application include virtual restoration of cultural heritage and artwork, region filling, object removal and so on [1,2,3,4,5,6,7]. Thangka as a living culture and an important cultural heritage, there are many treasures unique. But through the vicissitudes of life, some Thangka was serious damaged and the task of save, collation and study arduous will be very formidable. There is no doubt that improve the computer's processing capabilities in cultural heritage and artwork has important academic value, wide application of social and cultural development of great significance.

### 2.2 A digital restoration method for Thangka image

A new method is proposed for damaged image inpainting of Thangka image, which is combining the shape of damaged patches and type of neighborhood patches, according to the current algorithm characteristics of image inpainting, implementing automatic damaged regions inpainting.

#### 2.2.1 Shape classification of damaged patches

The first stage is segmentation and merger. The initial segmentation is to get the damaged regions of image through watershed method [8], but it is prone to over-segmentation, therefore the region merging is used.

Small regions merging:

- Step 1.** transform original image from RGB to LUV;
- Step 2.** compute the LUV mean value of initial segmentation regions;
- Step 3.** get each neighborhood of segmentation regions;
- Step 4.** merge the small regions with it adjacently in space and similar in color;
- Step 5.** update LUV mean value and neighborhood information of each small regions, up till inexistence the small region of area less than threshold  $T_a$ ;

Regions are merged to color close and space adjoins:

- Step 1.** compute the squared error of each small region with its neighborhood in LUV space;
- Step 2.** judge whether exist neighborhood patches that less than threshold  $T_s$  in the squared error, if present, then current small will be merged to the area of the least squared error, if not, do nothing;
- Step 3.** operate by repeated merging, until without the regions can be merged.

Through the above merger can restrain over-segmentation or less-segmentation effectively, where area threshold  $T_a$  and squared error threshold  $T_s$  need to be repetitious adjusted.

The next stage is shape classification of damaged patches.

Obtain the damaged patches. A mask image can be obtained through the damaged region segmentation, where each pixel is represent with 1 for damaged region and each pixel is represent with 0 for non-damaged region. Assumptions the mask image of damaged region

segmented as showing in Fig 1, the algorithm to get the damaged patches by region growing steps are:

- Step 1.** along the scanning line direction to scan the mask image, to initialize the mark of damaged patches:  $sign = 2$  ;
- Step 2.** Step 2. if the pixel value is 1, then the node add FIFO (First Input First Output), and the node value is updated to  $sign = 2$  ;
- Step 3.** Step 3. pop-up the first elements in the FIFO, make 4-neighbour or 8-neighbour region growing, if the pixel value of neighborhood is 1, then add FIFO, and its value is updated to  $sign$ , otherwise, do nothing, up till the FIFO is empty;
- Step 4.** Step 4.  $sign++$ , repeat Step 2 and Step 3, until the scanning finish all pixels of the whole image.

In order to prevent the confusion for damaged patches sign and damaged pixel mark, initialize  $sign = 2$ , all damaged patches sign will subtract 1 while find each damaged patches, and made the first damaged patches mark 1, The second damaged patches mark 2, and so on, the k damaged patches mark k. The pixel-set of pixel value 1 and 2 is mark of damaged patches and its number respectively, Fig 2 is damaged patches mark of Fig 1.

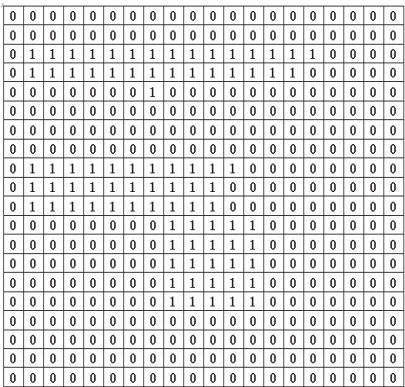


Fig. 1. The mask image of damaged region

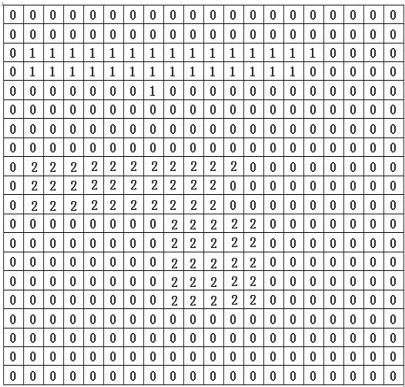


Fig. 2. Damaged patches mark of damaged patches

Shape classify to damaged patches. Studies show that the width or height of damaged patches can be repaired is  $T$  on non-texture structure inpainting algorithms, its range between 30 and 40. Moreover, texture structure inpainting algorithms can repair damaged image in a larger scale. Linear classifier as formula (1):

$$f(x) = \min(Mw, Mh) - T \quad (1)$$

Where,  $\min$  mean lesser,  $Mw$  and  $Mh$  denote width and height of the damaged patches,  $T$  indicate the maximum width or height that can be inpainted damaged patches for the method of non-texture structure; the damaged patches is linear while  $f(x) < 0$ , and the damaged patches is blocky while  $f(x) \geq 0$ .

### 2.2.2 Neighborhood classification of damaged patches

Image segmentation make whole image divided into mutually disjoint regions, texture information of neighborhood must be obtained when neighborhood classification of damaged patches. The situation of the neighborhood of damaged patches is roughly: (1) the around of damaged patches is texture region; (2) the around of damaged patches is non-texture region; (3) the around of damaged patches is mixed region, that is, have both texture region and non-texture region. Fig 3 is a schematic drawing that image segmented, where A, B and C is neighborhood patches of damaged patches.

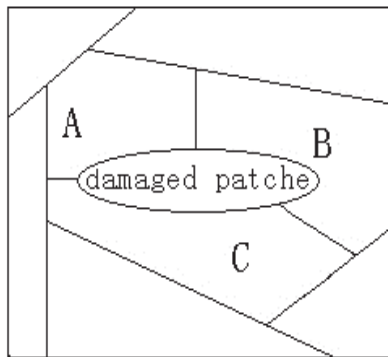


Fig. 3. Neighborhood patches

The algorithms of acquiring the neighborhood patches of damaged patches as following:

- Step 1.** get the outer-edge's mark of damaged patches, outer-edge is non-damaged pixels and inner-edge is damaged pixels;
- Step 2.** reject the iterative mark of edge, the remaining mark is the neighborhood's number of damaged patches;
- Step 3.** use the remaining mark as kernel points, adopt the method of region growing to get the neighborhood patches of damaged patches.

The current image inpainting algorithms are divided into two primary categories: texture and non-texture, therefore the neighborhood patches of damaged patches will be divided into: texture patches and non-texture patches, so that selection corresponding algorithm to repair a damaged image.

We use gray level co-occurrence matrix to extract two-order statistics information, and then extract texture feature of image.

Gray level co-occurrence matrix:

For any given a 2D image  $f(x, y)$ , and gray level  $Ng$ , then the size of gray level co-occurrence matrix is  $Ng \times Ng$ , each element of the matrix is defined by (2):

$$p(i, j) = \frac{\#\{(x_1, y_1), (x_2, y_2) \in S \mid f(x_1, y_1) = i, f(x_2, y_2) = j\}}{\#S} \quad (2)$$

Where, # denote the frequency of pixel point that satisfies some condition;  $(x_1, y_1)$  and  $(x_2, y_2)$  is space coordinate of pixel points, respectively;  $S$  expresses the set of pixel pair that have something space relation;  $i$  and  $j$  indicate gray value of pixel.

Due to symmetry properties of gray level co-occurrence matrix, generally only need to calculate in four direction:  $0^\circ$ ,  $45^\circ$ ,  $90^\circ$  and  $135^\circ$  respectively, and make finally features that have rotational invariance. Texture size is different for different texture image, also different on gray level co-occurrence matrix, therefore the various statistics of gray level co-occurrence matrix as texture features. Those statistics are angular second-order moment, contrast, relevance, entropy and inverse difference moment, respectively.

Angular second-order moment:

$$F_1 = \sum_{i=0}^{Ng-1} \sum_{j=0}^{Ng-1} p^2(i, j) \quad (3)$$

$F_1$  reflect the local uniformity of image, the bigger is the value, the more uniform is image texture; otherwise indicates the image have many transition level. Contrast:

$$F_2 = \sum_{n=0}^{Ng-1} n^2 \sum_{i=0}^{Ng-1} \sum_{j=0}^{Ng-1} p(i, j) \quad (4)$$

$F_2$  reflect the local variance of image, the value smaller for coarse texture, and the value larger for fine texture. If image is uniformity then  $F_2$  equal to 0. Relevance:

$$F_3 = \sum_{i=0}^{Ng-1} \sum_{j=0}^{Ng-1} \frac{ijp(i, j) - u_x u_y}{\sigma_x^2 \sigma_y^2} \quad (5)$$

Where,  $u_x = \sum_{n=0}^{Ng-1} i \sum_{i=0}^{Ng-1} \sum_{j=0}^{Ng-1} p(i, j)$ ,  $u_y = \sum_{n=0}^{Ng-1} j \sum_{i=0}^{Ng-1} \sum_{j=0}^{Ng-1} p(i, j)$ ,  $\sigma_x^2 = \sum_{i=0}^{Ng-1} (i - u_x)^2 \sum_{j=0}^{Ng-1} p(i, j)$ ,

$\sigma_y^2 = \sum_{j=0}^{Ng-1} (j - u_y)^2 \sum_{i=0}^{Ng-1} p(i, j)$ .  $F_3$  is similarity measurement between rows and columns in gray level co-occurrence matrix, which reflect the depends linearly relationship of gray. Entropy:

$$F_4 = - \sum_{i=0}^{Ng-1} \sum_{j=0}^{Ng-1} p(i, j) \lg p(i, j) \quad (6)$$

$F_4$  reflect the complexity of texture, the more complication is the texture, the more higher is the entropy; otherwise tend to low entropy. Inverse difference moment:

$$F_5 = \sum_{i=0}^{Ng-1} \sum_{j=0}^{Ng-1} \frac{p(i, j)}{[1 + (i - j)^2]} \quad (7)$$



$F_5$  is the reverse of contrast on gray level co-occurrence matrix, which measure the local consistency of image. If an image is approach uniform, the inverse difference moment tend to 1.

Calculate angular second-order moment, contrast, relevance, entropy and inverse difference moment in four direction:  $0^0$ ,  $45^0$ ,  $90^0$  and  $135^0$ , respectively, their expectation and variance as final features.

The size and rang of texture features is different, they are called heterogeneous feature, and need normalization process. Assuming there are  $M$  samples, features of each sample expressed as:  $(u_{Fi1}, u_{Fi2}, u_{Fi3}, u_{Fi4}, u_{Fi5}, \sigma_{Fi1}, \sigma_{Fi2}, \sigma_{Fi3}, \sigma_{Fi4}, \sigma_{Fi5})$ , where  $1 \leq i \leq M$ . Take one of the feature components for example, our improved Gauss normalization as following:

Let  $u_{F1j}$ ,  $u_{F2j}$ , ...,  $u_{FMj}$  indicate the  $j$  dimension feature components of  $M$  samples,  $u_{Fj}$  and  $\sigma_{Fj}$  denote expectation and variance respectively. The feature  $u_{Fij}$  can be normalized in  $(0,1)$  by formula (8) which play role is identical for each component.

$$N(u_{Fij}) = \frac{\frac{u_{Fij} - u_{Fj}}{3\sigma_{Fj}} + 1}{2} \quad (8)$$

The following is classification method of damaged neighbourhood.

Main inpainting algorithm generally is classified into two categories: structure-based inpainting and texture-based inpainting. The neighborhood patches of damaged patches are divided into texture, non-texture and mixed in our study, so that farther to select different algorithm to repair damaged patches according as they neighborhood patches. On the basis of the feature extraction of neighborhood patches make neighborhood classification of damaged patches, k-nearest neighborhood( KNN) method were taking place to classify neighborhood patches.

The classification on neighborhood patches of damaged patches based on feature of neighborhood patches. Suppose that there are  $M$  training samples, where,  $N_1$  belongs to texture category  $\omega_1$ ,  $N_2$  belongs to non-texture category  $\omega_2$ , and  $N_1 + N_2 = M$ . Now an unknown category sample  $X$ ,  $X$  belongs to  $\omega_1$  or belongs to  $\omega_2$ ? k-nearest neighborhood method is just to compute the distances between the  $X$ 's feature and  $M$  training sample's feature, and then sort the distances from small to big, to take the smaller  $K$  distances, and  $K$  is odd number. Finally, according to the category labeled of the smaller  $K$  distances vote to get the unknown sample's category labels. The vote method is: if the number more belong to  $\omega_1$  in the  $K$  samples, then  $X$  belongs to  $\omega_1$ , otherwise  $X$  belongs to  $\omega_2$ . Where  $K=9$ , which is determined by following experiment.

There are 100 training samples, 50 non-texture images and 50 texture images, 40 test samples include 20 non-texture images and 20 texture images. At first, extract feature of training samples through the previous methods, and then calculate the recognition rat of different  $K$ , at last, select an appropriate  $K$ . Table 1 is the results of experiment.

Table 1 shows: when  $K$  increasing, recognition rate is rising gradually, recognition rate have reached plateau when  $K$  soared to 9. Therefore  $K=9$  is better, this not only avoided a lot of

similarity calculation, but also can decrease the number of training samples and save memory space.

$K$	Recognition rate of non-texture	Recognition rate of texture	General recognition rate
1	70%	80%	75%
3	80%	90%	85%
5	90%	90%	90%
7	90%	90%	90%
9	100%	90%	95%
11	100%	90%	95%
21	100%	90%	95%
51	100%	90%	95%

Table 1. The recognition rate with different K for neighborhood classified of damaged patches

2.2.3 Restoration the damaged patches

Restoration method is founded on algorithm analysis, shape of damaged patches and neighborhood type, at same time, the type of damaged patches is established through its neighborhood. Combining shape of damaged patches, the type of neighborhood patches can achieve algorithm’s automatic selection when restoration a damaged image.

The proceedings will begin with, to construct algorithms library for Thangka image. There are four algorithms in algorithms library: design and implementation of algorithm 1 depending on the current exemplar-based image inpainting [7]; sampled-based texture synthesis be called algorithm 2 by [9,10]; algorithm 3 be designed by the Oliveira model [6]; and algorithm 4 is finished by TV or CDD model [2,3].

Secondly, algorithms are automatic selected based on the shape and type of damaged patches. The type of damaged patches based on the neighborhood are given in the form of define.

- Define 1. If the damaged patches have one neighborhood patches of non-feature, the type is called *damaged patches of homogeneous non-feature*.
- Define 2. If the damaged patches have more than one neighborhood patches of non-feature, the type is called *damaged patches of heterogeneity non-feature*.
- Define 3. If the damaged patches have more than one neighborhood patches of feature and non-feature, the type is called *damaged patches of mixed type*.
- Define 4. If the damaged patches have one neighborhood patches of feature, the type is called *damaged patches of homogeneous feature*.
- Define 5. If the damaged patches have more than one neighborhood patches of feature, the type is called *damaged patches of heterogeneity feature*.

Fig.4 shows our research result to select inpainting algorithm according to damaged patches shape and neighborhood type of damaged patches.



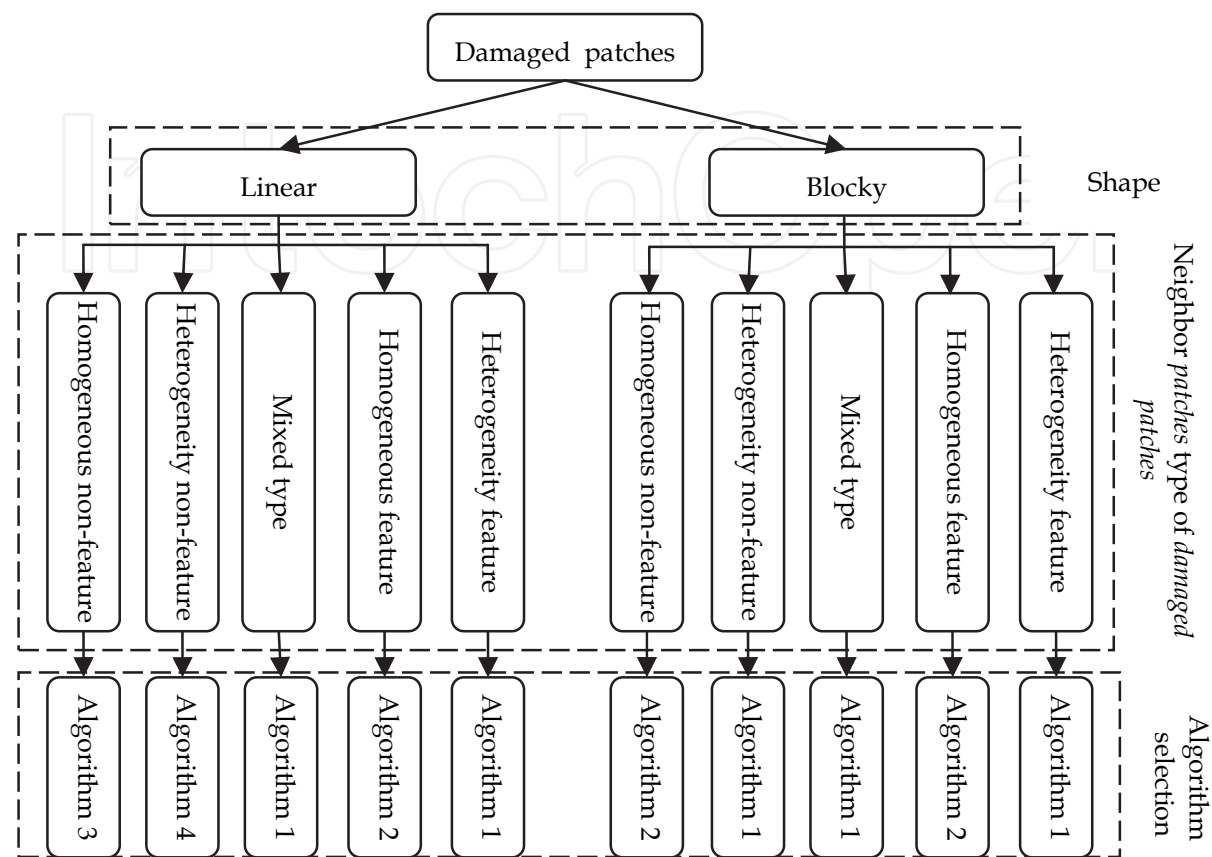


Fig. 4. Algorithm selection according to damaged patches shape and neighborhood type

Finally, inpainting process of damaged Thangka image based on damaged patches shape, neighborhood patches of damaged patches, characteristics of current inpainting algorithm, are given in the form of flow graph in Fig.5.

Through damaged region segmentation to get damaged patches, the reaction process is as follows when number of damaged patches is not equal to 0.

If the shape of damaged patches is linear, inpainting the damaged patches with Algorithm 1 when the neighborhood is heterogeneity feature or mixed type; inpainting the damaged patches with Algorithm 2 when the neighborhood of damaged patches is heterogeneity non-feature; inpainting the damaged patches with Algorithm 3 when the neighborhood is homogeneous non-feature; inpainting the damaged patches with Algorithm 4 when the neighborhood is heterogeneity non-feature.

If the shape of damaged patches is blocky, inpainting the damaged patches with Algorithm 1 when the neighborhood is heterogeneity feature, heterogeneity non-feature or mixed type; inpainting the damaged patches with Algorithm 2 when the neighborhood is homogeneous feature or homogeneous non-feature.

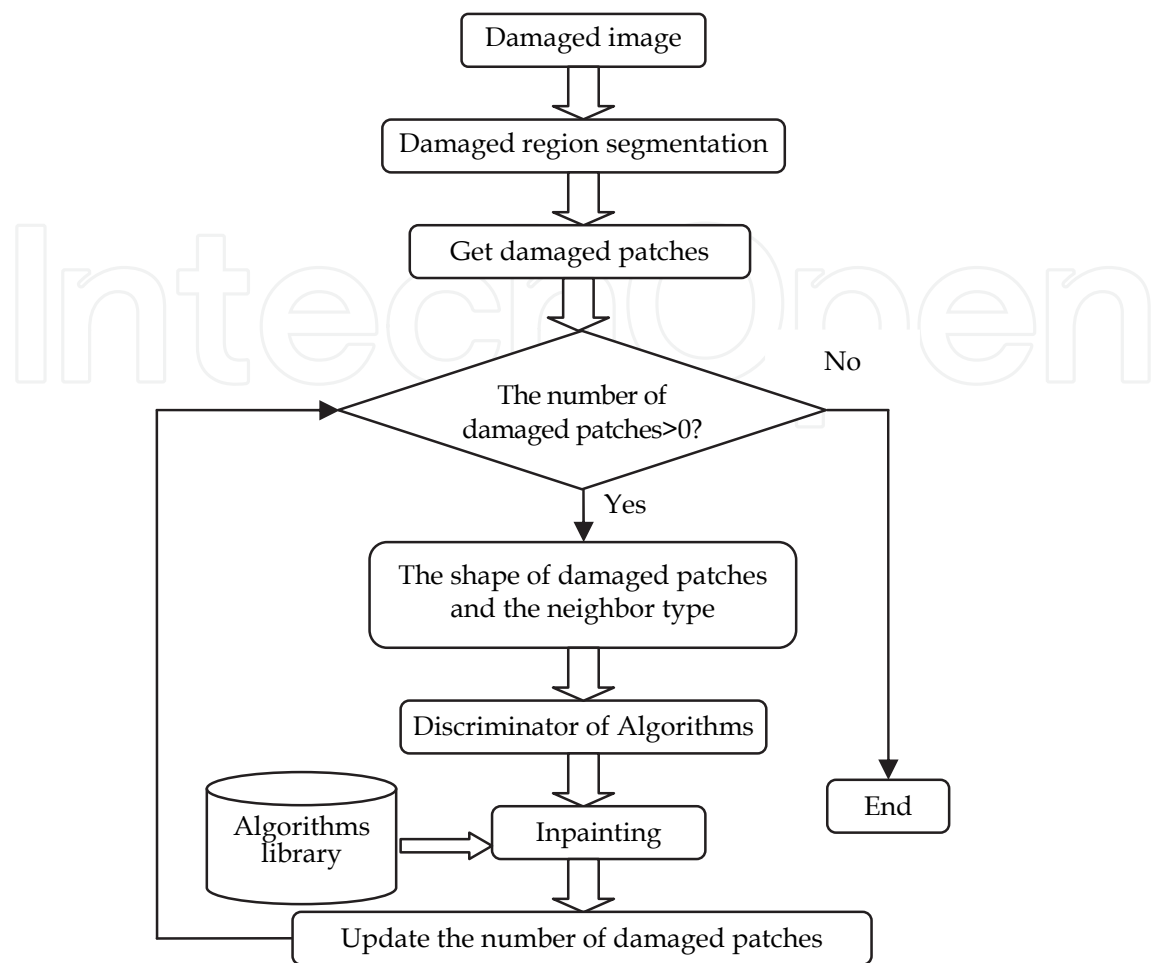


Fig. 5. Flow graph of inpainting process

2.3 Inpainting effect of damaged Thangka images

Some original damaged Thangka images show in Fig 6a, 6c, 6e on the left , Fig 6b, 6d, 6f on the right are corresponding inpainted results.

Fig. 7 shows some non-natural damaged Thangka images and their inpainted results.

In our research, experiment and analysis demonstrate:

1. Inpainting effect to non-natural damaged Thangka images was superior to natural damaged Thangka images.
2. Precision of selection algorithm is 80% which are affected by precision of neighborhood patches classified, correctness of segmentation damaged regions, and accuracy of damaged patches shape, however, segmentation is a predominant influence in the problem.

2.4 The current conclusion

1. In recent years, we have carried out research on this issue with related model of image inpainting, inpainting algorithm etc. [11,12], the study provides basis for this chapter in inpainting area of Thangka image.



(a) Damaged image



(b) Inpainted image



(c) Damaged image



(d) Inpainted image



(e) Damaged image



(f) Inpainted image

Fig. 6. Damaged Thangka images (local)



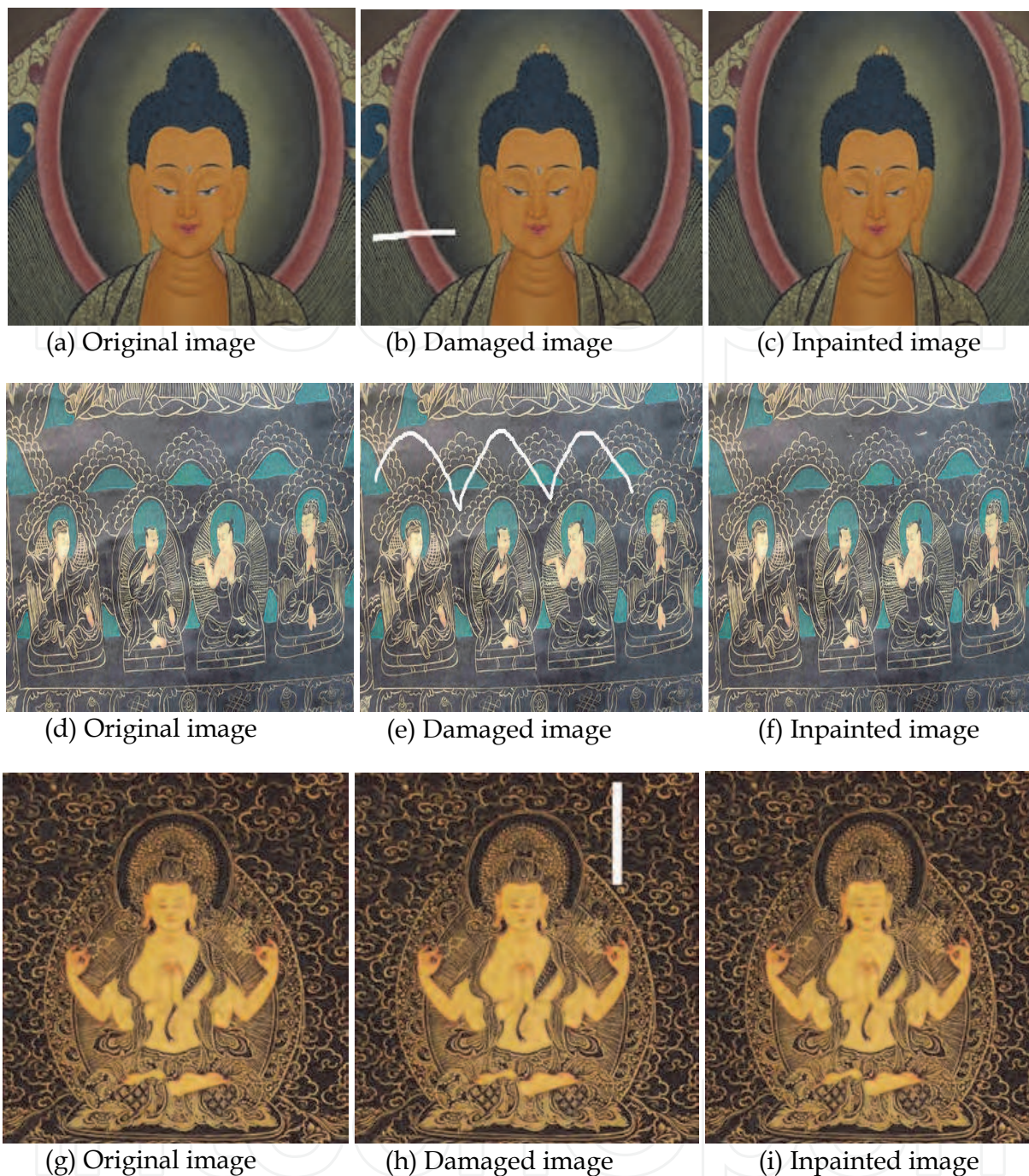


Fig. 7. Damaged Thangka images (local)

2. Improve and achieve current inpainting algorithm in Thangka image domain, these algorithm including exemplar-based inpainting algorithm, sampled-based texture synthesis algorithm, the algorithm based on the Oliveira model, CDD and TV model and so on.
3. The classification problem of damaged patches shapes was studied.
4. The classification of the neighborhood patches of damaged patches was studied, and damaged image was segmented by watershed algorithm in order to facilitate access to the adjacent information of damaged patches.

5. Implemented the automatic selection of inpainting algorithms combining the characteristics of different inpainting algorithms, the shape of damaged patches and the type of neighborhood patches.

There are a lot of correlative repair problem to need solution in damaged Thangka image, such as damaged region segmentation, obtaining damaged patches accurately, and effective inpainting the damaged patches. Main challenges for 2-D image inpainting lie in three aspects: domain complexity, image complexity and pattern complexity. Compared with all other image inpainting problems, for example, removal of occlusions, inpainting of old photographs, Thangka image's inpainting will be more difficulty due to the complexity of picture in the artwork domain. Furthermore, image segmentation of complex damaged and appropriate to Thangka image inpainting algorithm.

### 3. Construction of recourse repository of Thangka

This part researches on image knowledge repository for Thangka image based on the high level semantic about the attributes that describe the mains in the pictures. The attributes of mains are the domain knowledge that uses to establish the repository exactly, such as mains' name, headwear, appearance, complexion, mudra, talisman etc. Firstly, devise the conceptual data model of describing the mains depending on the attributes, show with relational schema of relational database. Secondly, build image libraries on the basis of the kinds, in accordance with the relational schema, use the non-automatic way acquiring knowledge, that is, devise a special knowledge editor to get knowledge, form various fact base for the kinds of mains and obtain fact knowledge for the repository. Thirdly, select some attributes that can typically distinguish mains depending on the characteristics of the mains attributes as key attributes, adopt production rule knowledge representation method, save the key attributes to be conditions and names of mains to be conclusions, form rule knowledge for the repository. At last, connect facts and rules by the process of knowledge query, combine forward reasoning control, and split strategies base in the light of the attribute of headwear, shape hierarchical conditions for production rule depending on execution sequence of key attributes for every strategy, take Structure Query Language of relational database to finish the reasoning work, provide strategy and rules in the process of reasoning and semantic introductions about the result image for users, construct Thangka image knowledge repository.

#### 3.1 Attribute database of Thangka image

Thangka are generally classified into five areas by the content of picture: all kinds of deities, human figures, Gesar, science and technology (building layout, astronomy calendar, Tibetan medicine, Tibet pharmacology), decorative pattern and so on. Take for case of religion, according to the status and identity of the main in Tibetan Buddhism culture, they have several kinds of them, including Buddha, Patriarch, Bodhisattva, Yidam, Buddha Mother, Arhat, Dakini, Dharmapala, Genius God and so on. The attributes of mains are the domain knowledge that uses to establish the repository exactly, such as main Buddha's name, headwear, appearance, complexion, mudra, talisman etc.

Fig 8a, 8b, 8c, 8d, 8e, 8f, 8g is Amitabha Pure Land, Songzan Ganbu, Jokhang, Gesar, The universe, Medical, The auspicious designs, they belong to seven categories: deities, human



figures, Gesar, building, astronomy calendar, Tibetan medicine, decorative pattern, respectively. Where, Fig 8h is a damaged Thangka image of local Yellow Kubera.

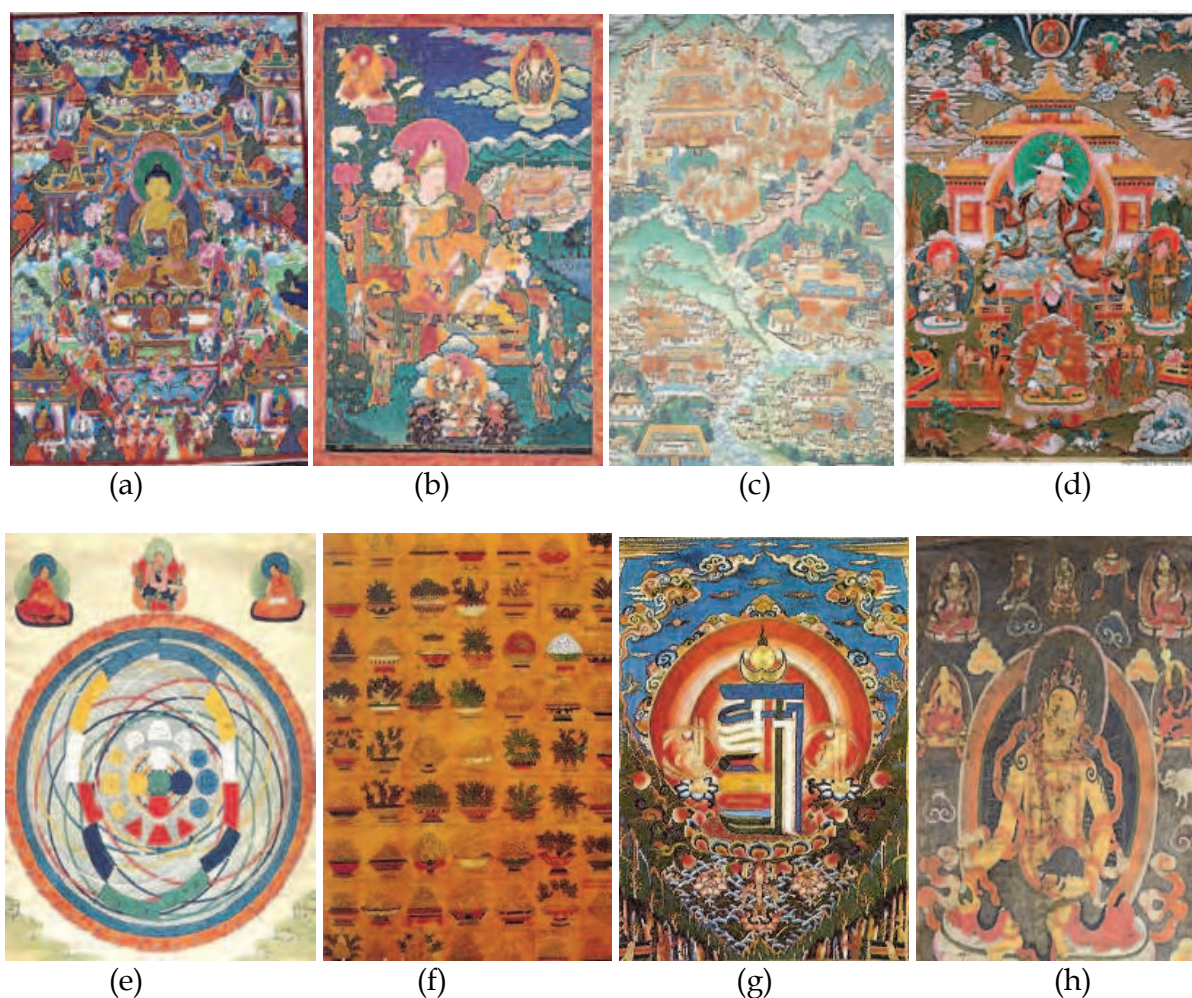


Fig. 8. Different classes of Thangka image

For example, take the Buddha. Attribute of Buddha category: appearance, complexion, headwear, pendant, dress, left-mudra, right-mudra, left-gesture, right-gesture, seat stand, setting posture, head light, back light, offerings, denominations, producing method, materials, works style, age, author, etc. they attribute values are identified as follows:

Appearance: anger, calm, less-huffish.

Complexion: yellow, red, blue, white and green.

Headwear: crown, bun, golden-crown, five-leaf-crown.

Pendant: treasure necklace, treasure rucaka, twin treasure necklace.

Dress: necklace of jade and pearls, cassock, Amai Mitsu.

Left or right-hand-mudra: mudra of teaching, dhyana-mudra, bhumisparsha-mudra, dharmacakra-mudra, varada, abhaya-mudra, lotus bud-mudra, mingwang-mudra.

Talisman: padma, prayer beads, dharma-cakra, bowl, sword, ten spoke wheel, spike flag, scape, net bottle, gold bottle, evergreen baoshu, saraca indica, flame ring wheel, vajra pestle, vajra rope, kancana-mandala.



Seat stand: padmasana throne, lion throne, padmasana and sun and moon disk, peacock throne, elephant throne.

Sitting posture: sitting meditation, hero posture, heroine posture, game posture, maharaja game posture, padmasana hero posture, vajra posture.

Head light color: green, black, red, transparence, orange.

Back light: yellow light disk, blue light disk, yellow and blue light disk, transparence, blue and red and yellow light disk, color light disk, green light disk, red light disk, gray light disk.

Offerings: bowl, fruit, padma, kapala bowl, aquarius, conch, jewellery, water, mirror, piano, cymbals, flute, milk, silk ribbon, Buddhist law wheel.

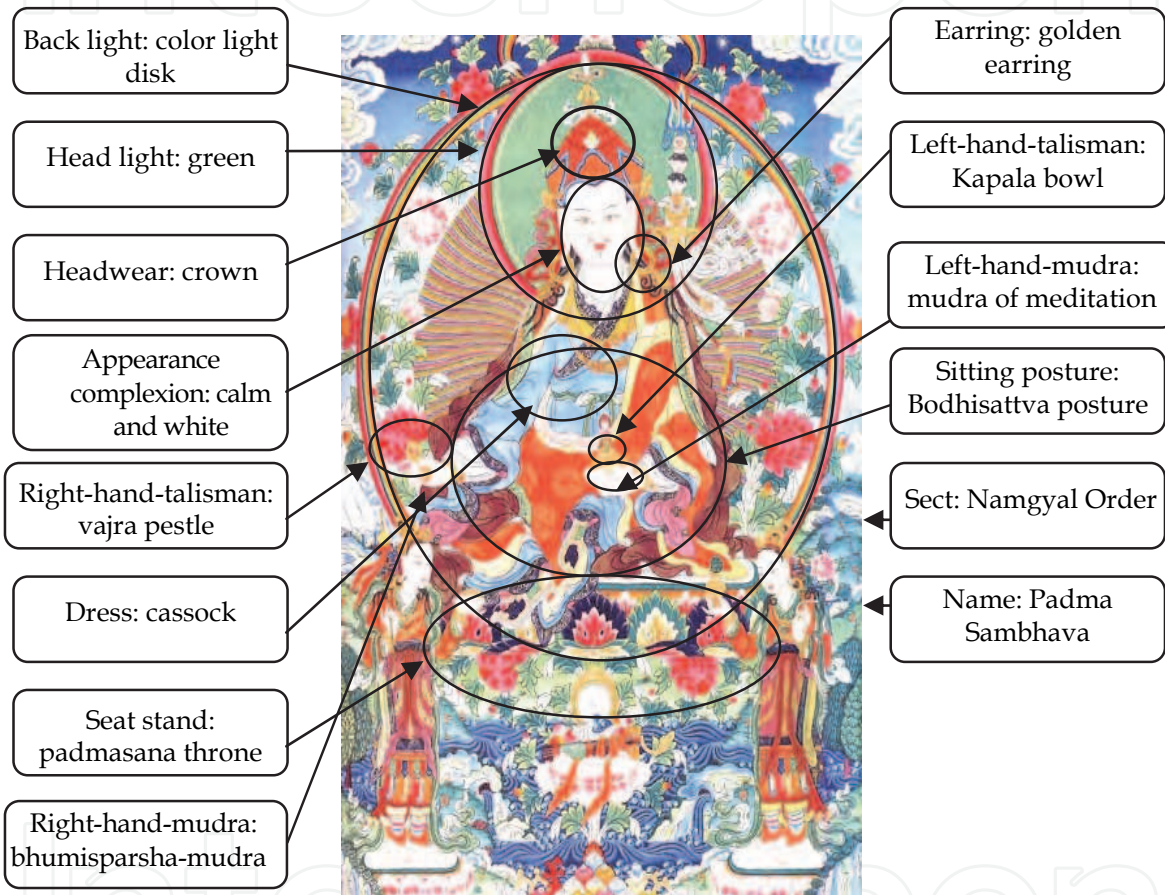


Fig. 9. Main attribute and attribute value

Sect: Namgyal Order, Sakya Order, Kadam Order, Kargyu Order, Gelukpa Order.

Production method: painting, barbola, embroidery, tapestry, appliqué, seed stitch, forme.

Materials: paper, cloth, shortening, timber, metal, stone.

Age: before sixteenth century, seventeenth century, eighteenth century, and after nineteenth century, unspecified.

The different category have different attribute item and attribute value. For instance, Fig. 9 show Padma Sambhava’s main attribute and attribute value for masters type.

3.2 Knowledge repository’s basic construction

There are sixe basic components in the knowledge repository of Thangka image:

1. Fundamental knowledge base. It is memory machine of factual knowledge and regularity knowledge
2. Knowledge reasoning. Inference mechanism is a set program that is used to control and coordination the knowledge base system, which derive the corresponding conclusion according to the fact and date of external input which are date of integrated database and fundamental knowledge base, by some inference strategy.
3. Interface of knowledge acquisition. Acquisition the domain knowledge from knowledge source to create fundamental knowledge base include fact and rule, the purpose of knowledge acquisition is to translate expert's domain knowledge for representation and reasoning of computer.
4. User interface. It is interface to achieve information exchange of knowledge base and outside.
5. Integrated database. it is working memory of knowledge base, which save with to be solved issue related initial conditions, fact, date, the various intermediate conclusions in reasoning process, objective conclusion etc.
6. Explanation mechanism. Its function is to provide rules and strategies in the process of knowledge reasoning aimed at query condition of user.

The core parts of the knowledge repository are fundamental knowledge base and inference mechanism. Knowledge repository's basic structure show in Fig 10.

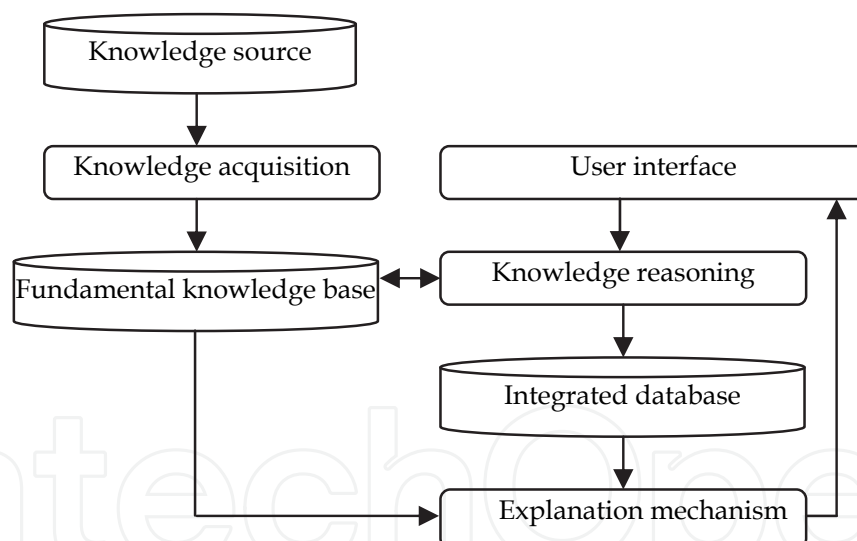


Fig. 10. Knowledge repository's basic structure

Interface of knowledge acquisition in Chinese, Fig.11 is the interface of selection of type, Fig.12 is the interface of knowledge input for Bodhisattva, some attribute value can be obtain through direct input or selection of drop-down menu.

Take for case of Buddha:

1. Select some attributes that can typically distinguish main Buddha depending on the characteristics of the main Buddha attributes as key elements, adopt knowledge representation method of production rule, save the key elements to be conditions and name of main Buddha to be conclusions, form rule knowledge for the repository.

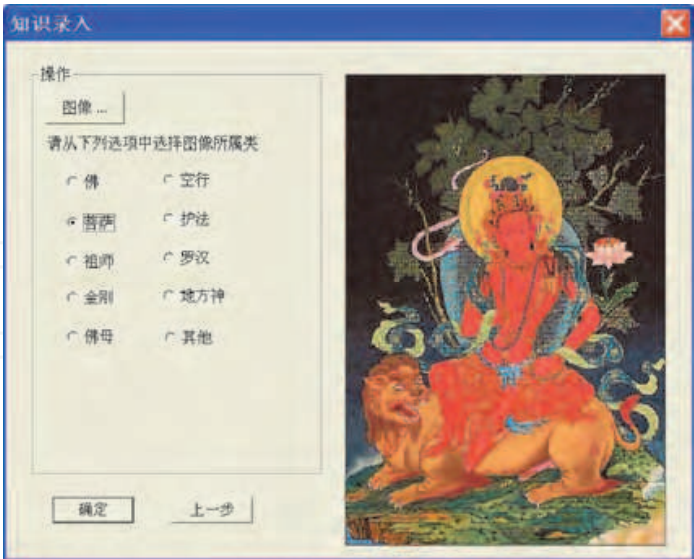


Fig. 11. Interface of knowledge acquisition of selection type



Fig. 12. Interface of knowledge input for Bodhisattva

2. Connect facts and rules by the process of knowledge query, combine forward reasoning control, and split strategies base in the light of the attribute of headwear, shape hierarchical conditions for production rule depending on execution sequence of key attributes for every strategy, take Structure Query Language of relational database to finish the reasoning work, provide strategy and rules in the process of reasoning and semantic introductions about the result image for users, eventually construct the Tibetan Buddhism Thangka Image Knowledge Repository.

Where, regularity knowledge is described by produce representation method of cause and effect, its basis form: IF conditions THEN Conclusions, which means is if the condition is

satisfied, then can launch the corresponding conclusion. Take image’s attributes as condition portion and the image as results section, and identify main Buddha by its title. Take the case of Sakyamuni Buddha, produce representation method of knowledge describe the connection of image and attributes, the rule as below:

IF	Headwear = bun	AND
	Appearance= calm	AND
	Complexion= yellow	AND
	Left-hand-talisman=bowl	AND
	Left-hand-mudra= meditation mudra	AND
	Right-hand-mudra= bhumisparsha-mudra	AND
	Dress=cassock	AND
	Sitting posture= meditation	AND
	Seat stand= padmasana throne	
THEN	Sakyamuni Buddha	

4. Thangka image annotation and retrieval semantic-based

4.1 The meaning and tasks of Thangka image annotation

It is the need of semantic-based Thangka image retrieval to establish an artifact annotation Thangka image database in a more object-oriented world. Thangka image annotation will be a heavy task with different classification, different content, and a picture with a lot of objects.

4.2 The current annotation methods and annotation contents

Take for case of religion of the main in Tibetan Buddhism [13,14]:

1. A headdress feature expression approach which mainly used contour feature and color feature are proposed. The average of spectral frequency represents contour feature. The color moment of internal contour represents color feature. Meanwhile, we can automatically annotate headdress concepts through computing variable quantity of spectral frequency and analyzing color distribution of internal contour.
2. A gesture feature expression method including five fingers directions, palm direction, relate position of gesture is presented. Because of the difficult features for segmenting gestures of Thangka image. Then, the concepts of unknown gestures can be predicted with nearest neighborhood method on the basis of training annotated gesture set.

4.3 Semantic retrieval framework of Thangka image

The process of semantic-based Thangka image retrieval includes five steps: (1) Identifying ROI (region of interested) of Thangka image; (2) Extracting visual features of ROI; (3) Training concepts classifier with concept dictionary and visual features; (4) Constructing C-K relation net; (5) Obtaining the retrieval result through using CSM algorithm on the basis of C-K relation net. This research focuses on step (4) and (5).

4.4 Construct C-K relation net

C-K relation net is a description to the membership degree of semantic keyword and relativity between semantic keywords as shown in Fig. 13; the lines between  $c_i$  (any



conception node) and  $k_j$  (any keyword node) indicate the membership degree between conceptions of keywords, the lines between  $k_j$  node denote the relationship of keywords, and the lines of same color indicate the keywords are correlative. The membership degree of some keywords belonging to a concept can be computed by the method of combining the Delphi method and fuzzy statistics, after artificial annotation to ensure the relativity between keyword and keyword. For example, the keywords “wisdom”, “sword of wisdom” and “enlightenment” belong to the concept “Sword”, and the membership degree which can be computed by subsequent methods are 0.45,1 and 0.85 respectively. Moreover, the keyword “wisdom” also belongs to concepts “Rosary”, “padma”, “Bow and Arrow”, and so on[15].

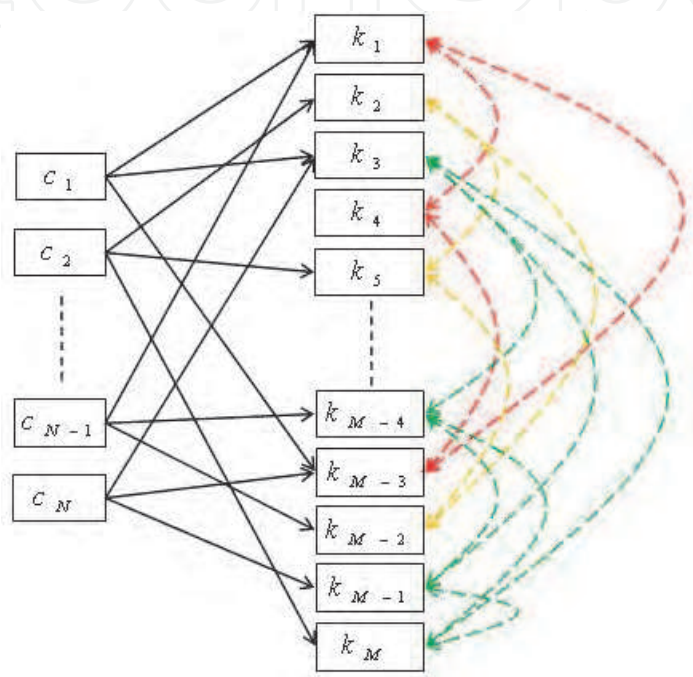


Fig. 13. C-K relation net

Suppose  $E_{i,j}$  is membership degree of the  $j$ th keyword to the  $i$ th concept, then  $E_{i,j}$  can be calculated:

$$E_{i,j} = \frac{\omega_1 D_{i,j} + \omega_2 F_{i,j}}{\omega_1 + \omega_2} \tag{9}$$

where  $D_{i,j}$  indicate the membership degree of the  $i$ th keyword to the  $j$ th concept by the Delphi method,  $F_{i,j}$  is the membership degree of the  $j$ th keyword to  $i$ th concept by fuzzy statistics,  $\omega_1$  and  $\omega_2$  are weighing coefficient.

The Delphi method, named by an ancient Greece city Delphi, is an expert survey of established procedure. Since 40s in 20th, it has been widely used in several fields such as economic management, psychology, sociology and so on. The characteristic of the Delphi method is concentrating the experience and advices of experts, to obtain the satisfying results by constantly feedback and revises. Semantic keyword is a description to conception in Thangka image, at the same time the membership degree of keyword to conception is different, besides, the emphasis to understand concepts is also different in various painting

school. Therefore, we adopt the Delphi method to calculate membership degree between semantic keyword and concept in this paper.

Supposed there are  $n$  domain experts, then  $m_{i,j}^k (k=1,2,\dots,n)$  indicate the membership degree of  $j$ th keyword to  $i$ th concept for someone expert's opinion. The average value of the membership degree can be calculated by (10), where  $a_k$  represents the weight of  $k$ th expert.

$$\overline{m}_{i,j} = \sum_{k=1}^n a_k m_{i,j}^k \quad (10)$$

And, the deviation  $m_{i,j}^k$  can be calculated by formula (11):

$$d = \sum_{k=1}^n a_k |m_{i,j}^k - \overline{m}_{i,j}| \quad (11)$$

To given error  $\varepsilon > 0$ , if  $d \leq \varepsilon$ , then  $\overline{m}_{i,j}$  as an approximate value of  $D_{i,j}$ ; if  $d > \varepsilon$ , then repeat the above process, until the precision is satisfied. Here  $\varepsilon = 0.19$

By statistic of the frequency of every semantic keyword appearing in the concepts and the method of membership functions mentioned above, we can calculate the membership degree of the semantic keyword to the concept.

In Thangka images, some semantic keywords are exclusive word to describe a concept, so the membership degree of the semantic keyword to the concept is high. On the other hand, some semantic keywords (including the ones have similar semantic) appear in several concepts, and then the membership degree of the semantic keyword to the concept is low. Based on the above characteristics, we propose a membership function as following:

$$F_{i,j} = \begin{cases} 1 & x_{i,j} = 1 \\ \frac{1}{x_{i,j}} + \beta & x_{i,j} \geq 1 \end{cases} \quad (12)$$

Where  $x_{i,j}$  is a frequency of the  $i$ th concept corresponding the  $j$ th keyword (include with similarity semantic keywords) in all concepts,  $\beta$  is correction parameter. The membership degree of  $j$ th keyword to  $i$ th concept decreases with the increasing of  $x_{i,j}$ , despite the decreasing of inverse proportion function  $\frac{1}{x}$  satisfies this relationship, it does not reflect the membership degree of keywords to concepts in quantity. Without correction parameter  $\beta$ , while  $x_{i,j} = 2$ ,  $F_{i,j} = 0.5$  indicates the description of membership degree of two keywords to  $i$ th concept, it is incorrect obviously. In this kind of situations, the membership degree is comparatively high. Therefore, correction parameter  $\beta$  is introduced to make the degree of membership function could more accurately reflect the degree of keywords to the concepts.



4.5 CSM algorithm

The main idea of CSM algorithm is to utilize membership relation of semantic keywords and concept, relativity of semantic keywords, to calculate the similarity. The procedures are as follows:

- Step 1.** in descending order, rank the membership degree of the semantic keyword which  $C_k$  is corresponding to.
- Step 2.** search whether there are  $C_{k,j}$  in other concepts or those have similar semantic to  $C_{k,j}$  in C-K relation net, if done, then ordinal execute, or else turn to Step 4.
- Step 3.** extract  $C_{k,j}$  appear in other concepts and those keywords have similar semantic to  $C_{k,j}$ , then from high to low, rank the membership degree of the concepts which the semantic keyword are corresponding to. Save the concepts to  $RC$ .
- Step 4.** determine whether the searching of semantic keyword corresponding to  $C_k$  is over. If done, then the arithmetic is over, or else turns to Step 2.

Where,  $C_k$  represents the concept waiting to be retrieved,  $C_{k,j}$  represents the  $j$ th keyword corresponding to the  $k$ th concept,  $E_{k,j}$  represents specific degree that the  $j$ th keyword subordinate to  $k$ th concept, and  $RC$  represents the set of similarity concepts which are retrieved finally. On the basis of C-K relation net, applying CSM algorithm to measure the similarity of concepts could meet the retrieval needs of customers better. Because this algorithm leans on C-K relation net, thereby, the efficiency of CSM algorithm will be influenced by the dilatation of C-K relation net.

4.6 Semantic-based retrieval

Semantic-based Thangka image retrieval was roughly classified into three layers in our research: (1) it is similarities of visual features that receive most attention on visual layer; (2) it towards coherence of key area’s concept on concept layer; (3) high level semantic retrieval place more weight on similarities of concepts. The experiment show that different retrieval layers can meet different users’ demand and outcome is satisfactory.

4.6.1 Thangka image retrieval based on the visual layer

Image retrieval based on the visual layer, that is, based on visual features of key region to make retrieval, its retrieval process show in Fig.14.

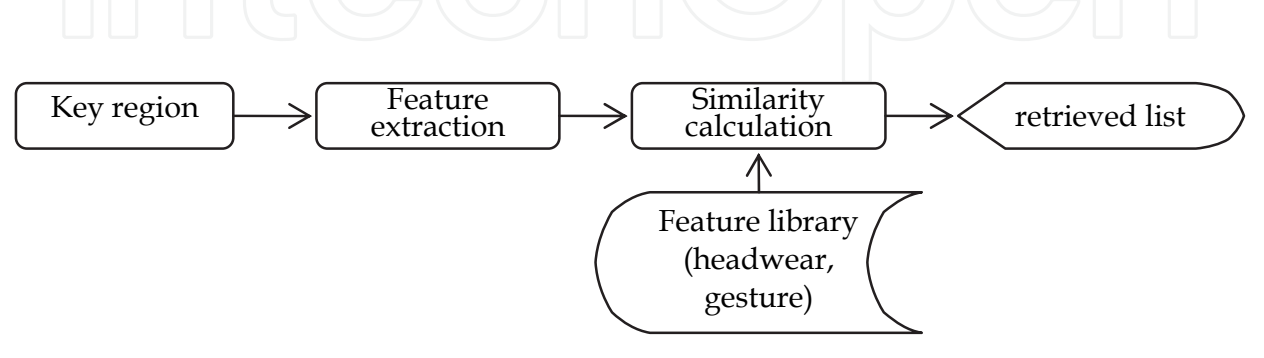


Fig. 14. Retrieval process of visual layer

Thangka image retrieval based on the headwear feature:

Headwear is an important characteristic in religion class portrait image, different headwear represent different category and have different meaning. First, the headwear’s feature you specify image was extracted; then to calculate the similar distances between specify image and database images of the headwear feature one by one, ascending sort the similar distances; finally, to get retrieval image by some algorithm. There are 236 images in Thangka image database, the number are 53, 65, 118 for headwear as monk hat, bun, crown, respectively. Use 20 Thangka images as test sample, where 5, 5, 10 images have monk hat, bun, crown respectively. The precision and recall ratio for the top ten, the top thirty, the top sixty, the top one hundred to see Table 2.

		The top ten	The top thirty	The top sixty	The top one hundred
Monk hat	precision	78%	56.67%	39%	32%
	recall ratio	16.25%	35.42%	48.75%	67.08%
Bun	precision	82%	71.34%	59%	46%
	recall ratio	13.67%	35.66%	59%	76.33%
Crown	precision	88%	81%	73%	69%
	recall ratio	8.15%	22.66%	39.63%	63.52%
Average	precision	83%	69.67%	57%	49%
	recall ratio	12.69%	31.25%	49.13%	68.98%

Table 2. Retrieval performance of headwear

Thangka image retrieval based on the feature of gesture:

As with the process of Thangka image retrieval based on the headwear feature, precision and recall of the retrieval result based on the feature of gesture is 78.63% and 71.06%, respectively. Retrieval based on the feature of gesture with better retrieval performance compare with retrieval based on the headwear feature, duo to geometrical features of gesture are relatively easy to match, but the similarity of headwear feature are calculated by contour and color which appear contour similarity, similar color in many cases.

4.6.2 Thangka image retrieval based on the concept layer

Thangka image retrieval based on the concept of key region:

That is what is called Thangka image retrieval based on the concept of key region, first identifying key regions and extraction corresponding feature you specify, where key regions are the objects of this article mainly aim at the headwear and gesture, respectively. Different objects or regions have different feature, automatic annotation the concept of key regions you specify, and then obtain the final retrieval result with a concept. The flow shows in Fig.15 as following.

Experiment result and analysis:

The result of this experiment was: if the concept of key region was correct estimated you specify image, then all of images of inclusion the concept can be retrieval in image database, that is, recall and precision is 100%; retrieval result, instead, will be irrelevant with you

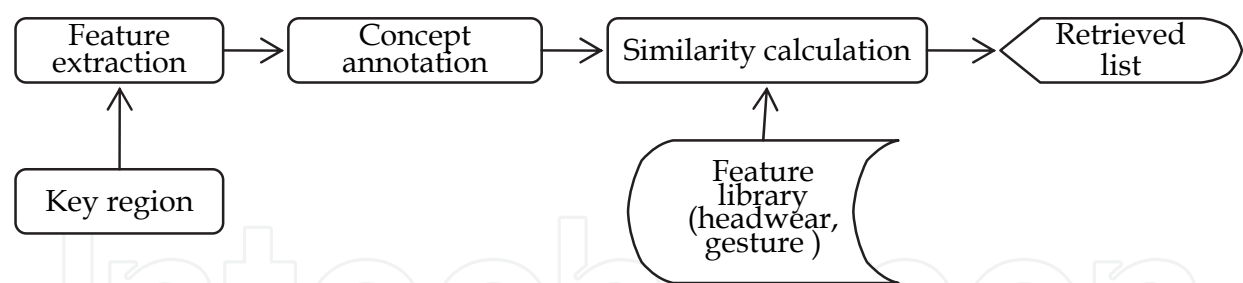


Fig. 15. Retrieval process of concept layer

specify image. In our experiment, there are 236 Thangka images in image database, test images 36, where 32 images' concept of key region was correct estimated, correct rate 88.89%. Therefore to improve the judging ability of key region's concept is very important, which need further study.

4.6.3 Thangka image retrieval based on C-K relation net

We employed 31 concepts, include 11 gesture and 20 musical instruments, 133 keywords. Each concept is described by several relevant keywords. First of all, annotate the interdependency of these 133 keywords by manual way, and construct *K-K* correlation matrix (keywords correlation matrix), where 0 indicates irrelevant and 1 indicates correlation. Because this part of experiment is pertain to natural language processing, thus, we apply manual annotation instead of analyze statistics of corpus. Second, six Thangka artists and six Tibetan teachers were invited to evaluate the membership degree that each keyword belongs to its relevant concept. The membership degrees were divided into three hierarchies, important, in general, and minor. The relevant weights of the three hierarchies are 1, 0.6, and 0.3 respectively. Applying Delphi method to appraise the evaluation and obtaining the final result of manual evaluation. And then, applying the degree of membership function this paper proposed to count the strength that every keyword belongs to other concepts based on *K-K* relation matrix. Composing manual evaluation and fuzzy statistics, we set the weight parameters  $\omega_1$ ,  $\omega_2$  to 5 and 3. Thangka images are a description to religion culture. Thereby, their content of semantic object is standard preferably. The fuzzy statistics calculate the membership degree through counting the number of concepts which are described by semantic keywords. Based on the reason above, we give more weight to the part of manual evaluation. Finally, we obtain the retrieval result with CSM algorithm based on the *C-K* relation net, part of retrieval result as shown in Table 3.

In the semantic retrieval of natural image, the concept of normal semantic object is minimum granularity, whereas the minimum granularity of Thangka image is the semantic keywords which corresponding to semantic concept. And, the similarity between concepts depends on the interdependency of semantic keywords. Based on this attitude, we proposed a novel method apply on high-level semantic similarity retrieval of Thangka image. Firstly, construct *K-K* correlation matrix by manual annotation, and composing Delphi method and fuzzy statistics to built *C-K* relation net. Secondly, it is easy to accomplish similarity retrieval between concepts in the *C-K* relation net with CSM algorithm. Experiments indicated that

the method can express the similarity relation between concepts accurately. However, this method only can satisfied similarity retrieval of concepts which inside the C-K relation net, and invalid for the retrieval of new concept.

Concept case	Retrieval result (top five)				
Tarjani-Mudra	Tarjani-Mudra	Hook-Mudra	Vajra-Vara	shield	Lotus
Anjali	Anjali	Lotus	Dhyana-Mudra	Humkara-Mudra	Dharmachakra-Mudra
Vajra-Vara	Vajra-Vara	Wisdom fist mudra	Eight-spoked dharma-cakra	Vajra bell	Trinacriform spear
Vajra bell	Vajra bell	Wisdom fist mudra	Rosary	Karma-vara	Lotus
Shield	Shield	Lotus	Sword	Humkara-Mudra	Hook-Mudra
Rosary	Rosary	Vajra bell	Shield	Spear	Lotus

Table 3. Part of retrieval result

5. Content-based Thangka image retrieval

The technology on content-based image retrieval (CBIR) is relatively mature, due to rich in color, picture complexity for Thangka image, however, some method for natural images are not always to suit Thangka image. A Thangka image retrieval system color-based and shape-based are intruduction.

Firstly, this part systematically studies extraction technology of visual characters about image’s low-rise. On the basis of that, the typical extraction methods of characteristics of color and shape are respectively studied. Retrieval system for color-based and shape-based Thangka image are designed and realized. In addition, during the process of extracting color characters, an improved method called local accumulative histogram based on HSV is come up with combined with traditional local accumulative histogram and Thangka image’s characteristics. Through many experiments, it shows that the color features seem to be more important than the shape features and the improved method called HSV-based local accumulative histogram is superior to traditional local accumulative histogram. Secondly, according to separate characteristics of color and shape, those two experimental retrieval systems are used to analyze the result Thangka image retrieval system. Then a comprehensive color-based and shape-based experimental retrieval system is designed and realized. After the experiment result analyzed, it is found that with comprehensive kinds of characteristics the efficiency of retrieving will be enhanced.

5.1 Retrieval framework content-based of Thangka image

A typical content-based Thangka image retrieval system as showing in Fig.16, which include two major contents[16]:

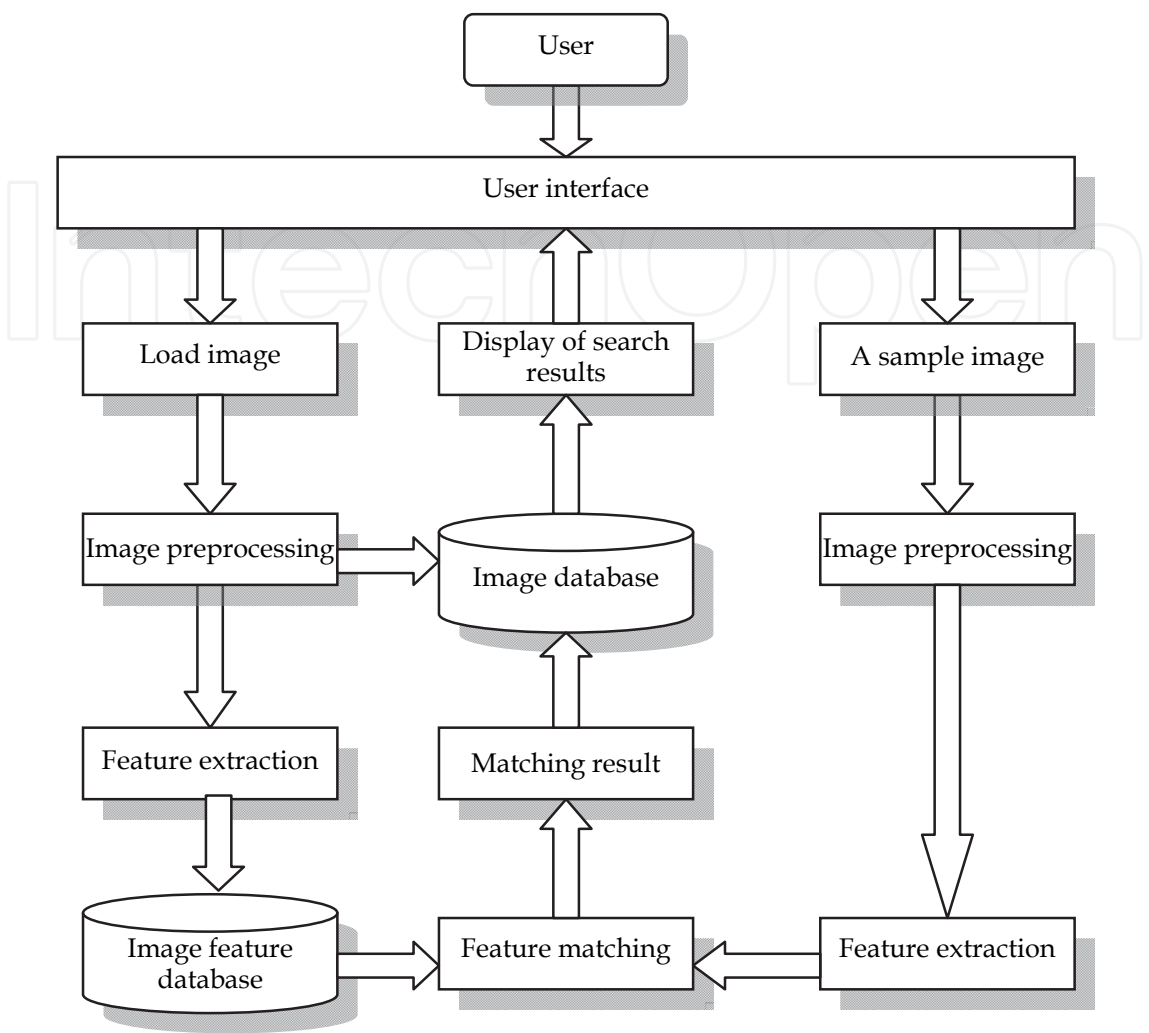


Fig. 16. Retrieval framework content-based of Thangka image

1. Establishment of Thangka image feature database. Left column from top to bottom, in Fig.16 establish the index mechanism between Thangka image database and Thangka image feature database.
2. Retrieving similar images. Right column from top, open a sample image or an image to be searched, the system obtain its feature by image preprocessing and feature extraction, then make similarity matching of feature between the specify image and database images, and the matching results are arranged in the order, in the top 20 search results will be feedback to the user.

## 5.2 Main contents

The key technology of content-based Thangka image retrieval is image feature extraction, this low-level vision features includes color, texture, shape and spatial relation etc. The retrieval methods for color-based and shape-based Thangka image are designed and realized. In addition, during the process of extracting color features, an improved method



called local accumulative histogram based on HSV is come up with combined with traditional local accumulative histogram and Thangka image’s characteristics. And a comprehensive color-based retrieval system and shape-based retrieval system are designed and realized.

5.3 Major results

1. The retrieval performance of feature color-based is superior to feature shape-based, and the retrieval performance of Color Moment-based is superior to other retrieval of color features.
2. An improved method of HSV-based local accumulative histogram which through to reasonably demarcate the HSV Color Space with second similarity measure is proposed, the retrieval efficiency are improved.
3. To achieve the color and shape of the multi-feature integrated search. Fig.17 is an interface of content-based Thangka image retrieval, to show the retrieval result by a sample image, and Fig.18 display top 20 similarity images.

6. Conclusion

The study aim of Thangka image’s digital is cultural heritage protection, main content include inpainting of damaged Thangka image, construction of resource repository and information retrieval of Thangka. Although our research had made some progress in the domain, there are also many issues to be studied in further, such as image segmentation of damaged, inpainting methods, Thangka image annotation, how to obtain domain knowledge by automatic and semi-automatic way in order to reduce the manual involvement, and a practical system platform of integration inpainting, content-based and semantic -based Thangka image retrieval, which can efficiently realize all kinds of query in Thangka domain, will be further research contents.

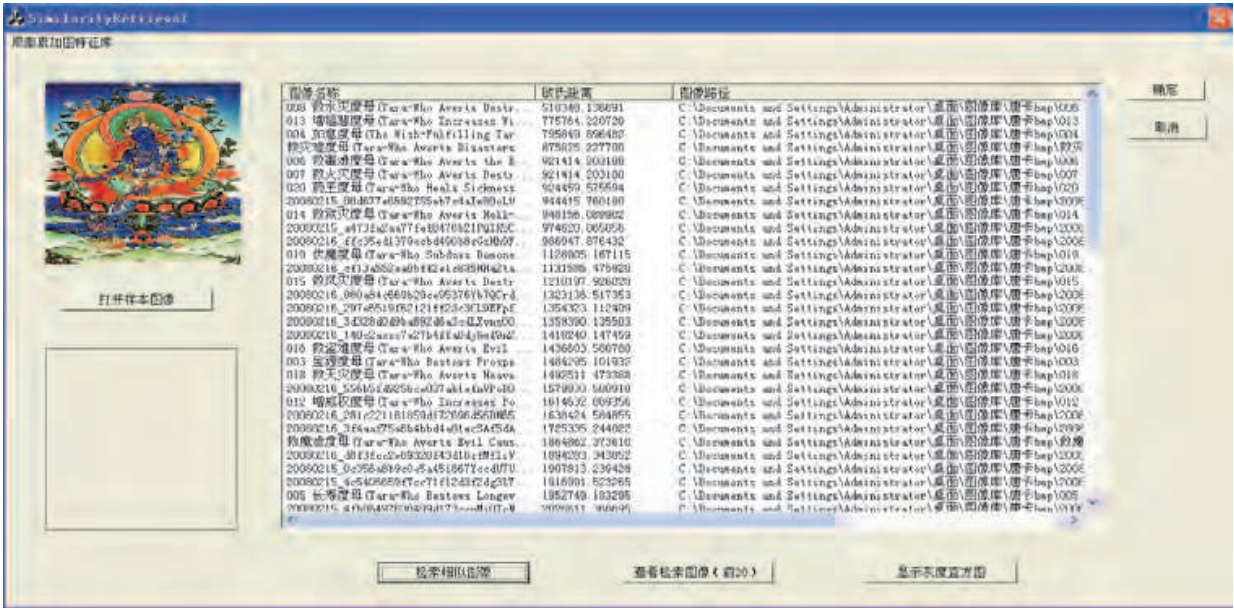


Fig. 17. Open sample image and similarity retrieval list



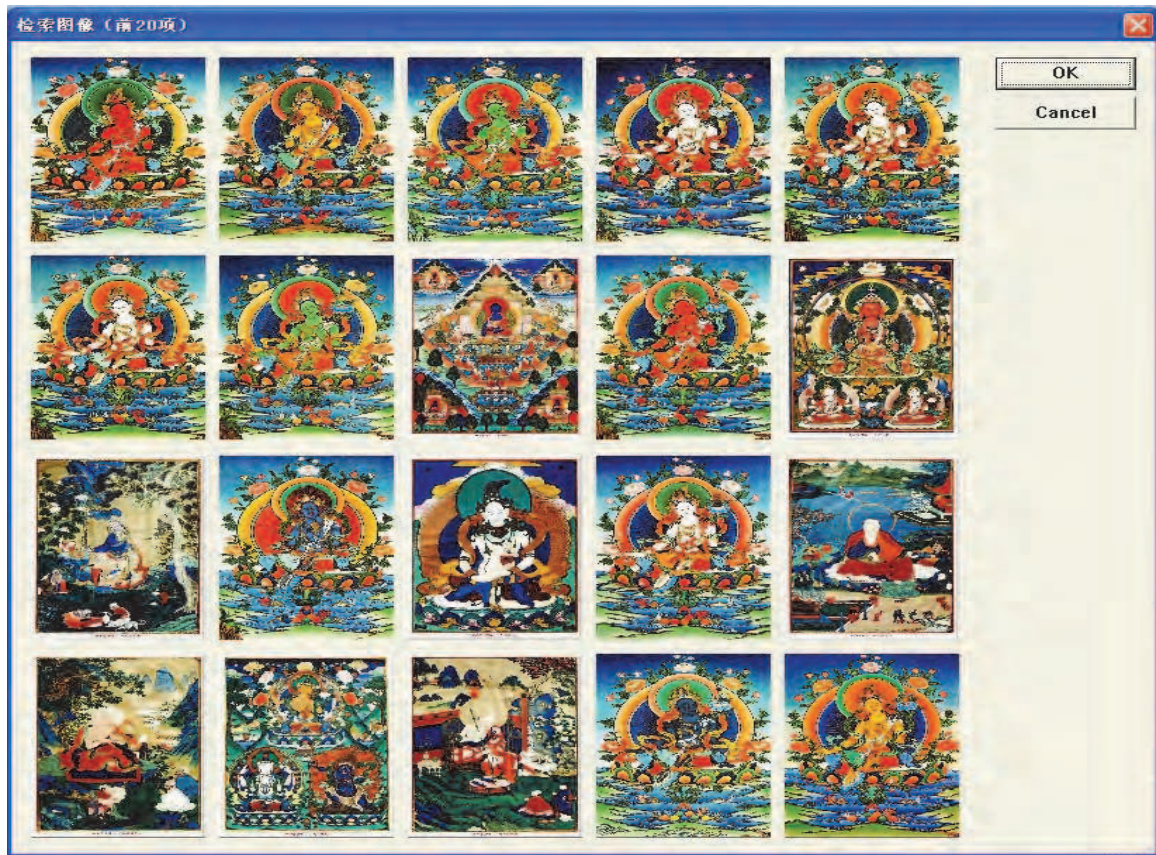


Fig. 18. Top 20 similarity retrieval list

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As multimedia has become a very important technology, significantly improving people's lives, this book provides an up-to-date scenario of various fields of research being carried out in the area. The book covers topics including web-based co-operative learning, effective distance learning through multimedia, quality control of multimedia on the internet, recovery of damaged images, Network-on-Chip (NoC) as a global communication vehicle, and Network GPS for road conditions (such as traffic and checkpoints). We believe that the book will help researchers in the field to proceed further in their research on multimedia.

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