Restoration of distorted digital images

and

similarity measure between images

By

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Abstract

In image processing field, restoration of distorted digital images and similarity measure between objects have obtained great attention over the years. Even numerous algorithms exist, the efficiency, accuracy and computing expense have been the major challenges to the researchers.

This thesis research reports the new efficient method to remove salt and pepper noises in the distorted digital images and a new informative method for detecting the similarities between images. The algorithm for noise removal in this thesis work is a preparation for segmentation. The algorithm is to use the mean value of the near neighbors to remove singularities. It is efficient for salt, pepper and thin line noise removal. Normally, 5 runs will be enough to obtain the desired result. The program can automatically detect when to stop the process and exit. It has been extensively experimented with many noisy images. The research on the similarity detection between images is the main research topic in this thesis. The proposal for this approach is to use 2D histogram of two images. An extensive research and experiments have been carried out for this research. A detailed discussion for each step is provided. It shall be a valuable reference for later research on the similar field.

An in-depth literature research on these research has also been done for comparison and reference purpose. Readers should find it informative and valuable for their research.

CONTENTS

Background & Introduction

This project research includes two major works. One is restoration of degraded images. The second one is the similarity measure between objects, which is also the main one of this project study. A brief review of these two fields research over the past years is presented here for reference and comparison.

1. Restoration of Degraded Digital Images

In the real life, images we often dealing with are not always ideal. The degradations of an image include two kinds. One is due to the imperfect real imaging system as well as imaging conditions. This kind of degradation are often obtained during the image acquisition due to imaging geometry, lens aberration, wrong focus, motion of scene, systematic and random sensor errors, etc. The second kind of degradations in a real image is the noises that are often introduced into images through imperfect maintenance environment and time length. The noise removal of a digital image is often the first step in image segmentation. A basic summary on the research of digital image restoration is presented as following:

- Image degradation caused by imperfect imaging system:

  The most popular approaches in this category are inverse and Wiener filtering[1], blind restoration[2-4], direct analysis[5] and invariant approch[6].

  The approach of inverse filtering[1] is to build the imaging equation by using block Toeplitz matrix. Using two-dimensional discrete Fourier Transforms of recorded image and point-spread function (PSF) matrix and under assumptions of low-contrast linear approximation valid, the signal-independent-noise and the locatable restoration effects in a segment cut from a large image, the inverse of two-dimensional block Toeplitz matrix can be solved from the imaging equation. Then the restoration of a degraded image is built from the inverse of two-dimensional block Toeplitz matrix. In case the inverse of two-dimensional block Toeplitz matrix doesn't exist, then inverse filter restoration does not exist. Inverse filtering approach is non-iterative and can be implemented by the use of Toeplitz Fourier computation. On the other hand, Wiener filtering[1] is more emphasizing in one-dimensional signal processing. Wiener filtering is a multiplicative noise process that is opposite to additive algorithm noise process. Inverse filtering and Wiener filtering approaches have achieved certain success in restoring degraded image from high signal-to-noise ratios and moderate blurring degradation. However when the concurrence of moderate blur and a low signal-to-noise ratio constitutes a problem in an image degradation, inverse filtering fails and Wiener filtering produces less desirable result.

Blind image restoration has been discussed extensively in the literature. It is the process of estimation both the original image and the PSF from the degraded image using partial information about the imaging system. Well-known groups in this method are parametric method[2], stochastic process[3] and project-based approch[4]. Parametric method, which assumes that a parametric model of the PSF is given a priori and the unknown parameters can be estimated by investigating the zero patterns of the Fourier transform, was first introduced in 1987 and further developed in 1990 by R.H.T. bates research group[2]. This method is based on the properties of Z-transform. It was proven that the zeros of the Z-transform of each ideal image and PSF lie on distinct continuous surfaces called zero sheets. Separating these two zero sheets from each other, we can restore both ideal image and PSF up to a scaling factor. The weakness of this method is in its numerical implementation which is very sensitive to noise and time-consuming. Another group of parametric method approach is based on modeling of the image by a stochastic process. The original image is modeled as an autoregressive (AR) process and the blur as a moving average (MA) process. The blurred images is then modeled as a mixed autoregressive moving average (ARMA) process and the MA process identified by this model is considered as a description of the PSF. In this way the problem of the PSF estimation is transformed onto the problem of determining the parameters of an ARMA model. This approach suffers from the computational complexity of which could be extremely high. Project-based approach of the parametric method attempts to incorporate prior knowledge about the original image and the PSF through constraint sets. This method was proven to perform well even if the prior information was not perfect. The drawback of this method is that there is no unique solution.

Direct-analysis[5] of the degraded image is based on the different idea which in many cases one doesn't need to know the whole original image, one only needs for instance to localize or recognize some objects on it. Typical examples are matching of a template against a blurred aerial image or recognition of blurred characters. In such cases, only knowledge of some representation of the objects is sufficient. However, such a representation should be independent of the imaging system and should really describe the original image, not the degraded one. In other words, they are looking for a function I which is invariant to the degradation operator. Particularly, if the degradation is described by equation $g(x,y)=f(f*h)(x,y)$, where f(x,y) stands for the ideal image, and g(x,y) is the degraded image, then the equlity I(f)=I(f*h) must hold for any admissible PSF.

The new approach, invariant approach[6], to the problem of restoration of degraded image was reported in 1998 by the same research group in the direct analysis of parametric method. This approach derives the features for image representation, which are invariant with respect to blur regardless of the degradation PSF provided that it is centrally symmetric. The report also proves that there exist two classes of such features: the first one in the spatial domain and the second one in the frequency domain. The invariant in the space domain is based on the image moments. This invariant can be built in any order and can be expressed in the explicit form. The invariant in frequency domain is investigated by using Fourier transform convolution theorem. The combined invariant, which is invariant to composite geometric and blur degradations, is derived and used to recognize objects in the degraded scene without any restoration. For computer implementation of this approach, the definition of the image moments is converted into discrete domain. Usually for a coarse level restoration, only a few invariants are used, but for a fine restoration, more invariants, which is in the neighborhood of hopeful location, are involved. The potential application of this approach is in object recognition in blurred and noisy environment, template matching and image registration. The still-exist-problems are that the derivation of combined invariants and higher order image moments are over complicated and time consuming.

- Degradation caused by noise

In this category, most common noises are salt and pepper, sand and Gaussian noises. This kind of degradations is often introduced into images through imperfect maintenance environment and time length. The restoration of such degraded images has been a major research topic in image processing field and attracted great attentions for past years. Most approaches to this problem are based on Gibbs distributions and MRF (Markov Random Fields) theory. Among numerous existing models, two main reported methods are worthy a brief review here.

1984 Stuart Geman and Donald Geman first reported a theory on the image restoration by using stochastic relaxation, Gibbs distribution and MRF[7]. They adopt a Bayesian approach and introduce a "hierarchical" stochastic model for the original image, based on Gibbs distribution, and a new restoration algorithm, based on stochastic relaxation and annealing, for comparing the maximum a posteriori (MAP) estimate of the original image given the degraded image. This algorithm is highly parallel and exploits the equivalence between Gibbs distributions and MRF. The essence of the approach to restoration is a stochastic relaxation algorithm which generates a sequence of images that converges in an appropriate sense to the MAP estimate. This sequence evolves by local (and potentially parallel) changes in pixel gray levels and in locations and orientations of boundary elements. Deterministic, iterative-improvement methods generate a sequence of images that monotonically increase the posterior distribution (the "objective fu

contrast, stochastic relaxation permits changes that decrease the posterior distribution as well. These are made on a random basis, the effect of which is to avoid convergence to local maxima. This is different from "probabilistic relaxation" which is deterministic. The stochastic relaxation algorithm can be informally described as follows.

1) A local change is made in the image based upon the current values of pixels and boundary elements in the immediate "neighborhood". This change is random and is generated by sampling from a local conditional probability distribution.
2) The local conditional distributions are dependent on a global control parameter T called "temperature". At low temperatures the local conditional distributions concentrate on states that increase the objective function, whereas at high temperatures the distribution is essentially uniform. The limiting cases, T=0 and T=∞, correspond respectively to greedy algorithms (such as gradient ascent) and undirected (i.e., "purely random") changes. (High temperatures induce a loose coupling between neighboring pixels and a chaotic appearance to the image. At low temperatures the coupling is tighter and the images appear more regular.)
3) The image restorations avoid local maxima by beginning at high temperatures where many of the stochastic changes will actually decrease the objective function. As the relaxation proceeds, temperature is gradually lowered and the process behaves increasingly like iterative improvement. (This gradual reduction of temperature simulates "annealing", a procedure by which certain chemical systems can be driven to their low energy, highly regular, states.)

The “annealing theorem” prescribes a schedule for lowering temperature which guarantees convergence to the global maxima of the posterior distribution. In practice, this schedule may be too slow for application, and it is used only as a guide in choosing the functional form of the temperature-time dependence. The stochastic relaxation algorithm used is a “heat bath” version of the Metroplis algorithm[8]. The idea of introducing temperature and simulating annealing is due to Cerny[9] and Kirkpatick[10] et al, both of whom used it for combinatorial optimization, including the traveling salesman problem. Kirkpatrick also applied it to computer design. Since the approach is Bayesian model-based, with the “model” captured by the prior distribution. The models are “hierarchical”, by which it means layered processes reflection the type and degree of a priori knowledge about the class of image under study. The model and estimate reported are noncausal and nonlinear, and do not represent extensions into two dimensions of one-dimensional filtering and smoothing algorithms. The approach is very flexible. And the degradation model is almost unrestricted; in particular, it allows for deformations due to the image formation and recording processes. However it is intensively mathematics involved. The implementation is difficult to be achieved. The cost of the computation could be very high.

Seven years later in 1991, Valen E. Johnson etc. reported another important approach to this problem which uses Gibbs priors to deal with boundary modeling, treatment of blurring and selection of hyperparameter[11]. Since many imaging systems produce images that are based on counts of photon emissions and these images suffer from two major sources of image degradation. The first source of degradation arises from variation in the number of photons emitted by the object under study. This approach assumes that the number of counts emitted during a finite interval of time follows a Poisson distribution, and that it is the mean intensity level of the Poisson distribution that is of interest. Hence, one objective of the restoration algorithm is to reduce the effect of the variation of the observed counts on the processed image. This can be accomplished by smoothing or averaging counts arising from nearby locations, but to do so indiscriminately results in an image in which boundaries between distinct regions cannot be identified. Smoothing should therefore be restricted to homogeneous regions, and so estimation of boundaries within the image is also required. For this reason, this report proposes an expansion of a model proposed by Geman and Geman[7] to account for edges or boundaries within the image. The modification from Geman's model is that the line sites are continuous and take values in the interval [0, 1]. This allows a simple variation of the method of iterated conditional modes to be used to obtain point estimates of the image. Another objective of this report is the restoration from Blurring problem, which is a degradation of spatial resolution that is caused by sensor limitations and misdirection or scattering of photons prior to their registration as detected events. The important aspect in recovering the information from blurring is that the neighborhood system and potentials of the Gibbs prior must be matched to the blurring width. And this problem is efficiently treated in the context of an incomplete data problem. In a summary, even this report has incorporates many ideas from previous work, it has new features of its own. One such feature is modeling the Poisson intensities on the square root scale. Because this is the variance stabilizing transformation for gamma likelihood functions, the amount of smoothing need not be adjusted according to the magnitude of the estimated intensities.

More importantly, the transformed likelihood is easily combined with as Gibbs prior, and the resulting posterior yields conditional distributions for the intensity sites that are Gaussian. Hence, samples from the image can be drawn quickly, and the conditional posterior mean can be easily determined. Another important aspect of the model is the inclusion of continuous line sites. By using continuous line sites, point estimates from the posterior can be obtained with only a moderate amount of computational effort. Additionally, continuous line sites have the effect of automatically adjusting the amount of smoothing according to the roughness of the observed counts. Thus, regions in which the observed counts exhibit little variation are smoothed more than those regions in which there is more variation in the observed counts. Finally, the effects of blurring are handled in two ways. First, the restoration algorithm is framed as an incomplete data problem. Although the blurred intensities could be modeled directly, the model is greatly simplified by treating the unobserved, unblurred counts as latent data. Not only does this simplify the formulation of the prior, it also reduces the computational burden associated with obtaining restorations. Second, the neighborhood system associated with the Gibbs prior was expanded to include cliques and potentials roughly the width of the PSF. This expansion permits the detection of boundaries within the image even after substantial blurring has occurred. However, the implementation of the model requires further investigation. One aspect is the convergence properties of the ICA algorithm. Although it can be demonstrated that the ICM method always converges to a local maximum of the posterior distribution, the convergence properties of the ICA algorithm are not known. Also, optimal strategies for decreasing the smoothing parameters when implementing the ICA method need to be determined, and more efficient methods for performing cross-validation should be investigated.

2. Similarity Measure Between Images

Object similarity detection among images is effortless nature aspects of humans, but still remains a big challenge to computer systems. Object similarity detection could have very potential applications in remote sensing, automatic personalization of environments, and criminology and security systems, which are characterized by face recognition. Face recognition is a key problem in this field and has obtained certain success over the years. Face is a unique feature of human beings. Even the faces of identical twins differ in some respects. One needs to locate, identify and distinguish between faces with very casual inspection. The uniqueness of faces is also the reason for their widespread use in applications where identification of people is important. A system to correctly locate and identify human faces would be useful in several applications. It can be used for identification of criminals, as we mentioned above. It can also be used for authentication in secure systems. Examples of such systems include computer systems and bank teller machines. Virtually all facilities that allow access based on the identification of the person fall into this category. Many systems currently use such items as cards, code numbers, and/or passwords to allow access. A system based on face recognition will be much more robust and much less inconvenient. Some other applications in which face recognition has been used include assistance in speech recognition, in systems for better man-machine interaction and in visual communication over telephone and other low ban-width lines. However it still remains to be established just how unique facial appearance is, and whether algorithms can be designed that might approximate the face recognition performance of humans, for whom error are slightly (but now much) below one percent. It remains to be seen whether computer vision algorithms can pass this same test. However there are numerous models exist for this effort. The reported technologies for face recognition can be summarized as back-lighting[12], Zernike Moments[13], Distributed Associative Memories (DAM)[14], Templates[15], Local Invariants[16], local Autocorrelations and Multiscale Integration[17], Changes in Illumination[18], Single Front View[19], Caricaturing[20], Neural Network[21], and Fuzzy Pattern Matching Method[22]. The following is a brief review of each technology mentioned above.

In 1990, after many times failure of trying to develop computational procedures for face recognition, Chyuan Jy Wu and Jun S. Huang[12] from computer vision laboratory in Institute of Information Science of Academia Sinica in Taiwan realized that all the lighting intensity difference on the face, cosmetics, oil, dirt, or hair covering could lead to the failure of the face recognition. After another time period of hard study, they finally obtained the desired success in developing face recognition by profile analysis using back lighting method. They start with taking a profile image by direct photography with back-lighting and obtain the outline curves automatically, not by an artist's drawing. The B-spline was used to extract some interesting points (or turning points) on the outline curve and then from these interesting pints obtain six interesting points. From these six interesting points 24 features were obtained. For each person, three face images are taken and each feature's mean and standard deviation are calculated. This is the learning mode. In the recognition mode, the input feature vector to the library files established during the learning process is matched. The match of a person will be rejected if most of features fall outside 3 s.d.s or one feature falls outside 20 s.d.s (an outlier based on heuristic choice). 18 people with typical faces from small to large and from young to old are chosen for recognition tests. The recognition rate was nearly 100% based on the minimum weighted distance criterion. In order to build an efficient recognition system, the system needs to be trained to learn first. Then the convincing sample representatives are prepared and asked to sit on a predsigned chair. Three profiles of each person are taken. And at each different imaging time the person was allowed to move his/her head slightly. All the profiles taken then will be stored in the computer system. If an unknown person's profile image is input to the system, the system extracts its 24 features and match these features against what are stored in the feature file, by sequential search. If the unknown person's 24 features satisfy five conditions the system will not reject the match and will print out the matched person's name. The five conditions are 1) for five input distance features, at least three of them fall within the corresponding confidence intervals. 2) for four input angle features, at least three of them fall within the corresponding confidence intervals. 3) for five input length features, at least three of them fall within the corresponding confidence intervals. 4) for five input summation of curvature features, at least four of them fall within the corresponding confidence intervals. 5) for five input symmetrical measure features, at least four of them fall within the corresponding confidence intervals. This is the early model of neural network technology on face recognition. The test result of the system indicates that this system is reliable and has achieved nearly 100% recognition rate. The problem is that the requirement on the input images is very restrict and not realistic. The system can only be successful in the ideal situation. However this report has offered a valuable reference for later improvement on the research of this field.

Meanwhile the neural network[13] is progressing, other approaches are also on the way. Aleireza Khotanzd and Yaw Hua Hong also reported their success in a completely different approach as neural network on face recognition[13] in 1990. The study is using Zernike Moments, a class of orthogonal moments, and can recognize faces in a scene regardless of its position, size, and orientation. The aim of the work is to develop new features along with a systematic method for selection of the required number of features needed. A new set of features defined on the Zernike Moments, which are a mapping of an image function onto a set of orthogonal basis functions over the unit circle, are developed first to help the later recognition process. These features are the magnitudes of complex Zernike Moments and are proven to be rotation invariant, and also the orthogonality property of Zernike Moments makes the image recognition from its moments computationally simple. Then it evaluates the image representation ability of each order moment as well as its contribution to the reconstruction process. A systematic method for selection of the required number of features in a classification problem is also developed. The selected number for the highest order moment is the one which yields a reconstructed image which is close to the original one. The discrimination power of the proposed Zernike Moments features and the developed feature selection method are tested by a series of experiments on two different data sets using a nearest-neighbor as well as a minimum-mean distance classifier. The considered images have differences in scale, translation, and rotation. They are first normalized with respect to scale and translation using regular moment based techniques. The obtained classification accuracy for a 26-class character data set is 99%, while a perfect recognition rate is reported for 4-class lade data set. This approach is effective for the image classification problem. But the problem is that it is extremely difficult to select and implement the calculation on highest order moment. The complexity is the main drawback.

In the same year, 1990, another group of researchers, W. Polzleitner and H. Wechsler[14], has also reported the achievement on the face recognition using distributed associative memories (DAM) [14.] This report has opened a new view to the researchers who have been working on this problem for years. This report views the recognition problem as an indexing problem, i.e., the access to a memory by its contents rather than by addressing plays a central role. An object is presented to a memory which than outputs the address (or classification) of the object. A model for such a system is that of the distributed associative memory (DAM). In this model pairs of key stimulus and response vectors are associated via a matrix operator. Retrieving information from memory is performed by multiplication of the unknown key vector with the memory matrix. The resulting output vector (the recall or recollection) is a particular stored data vector or an approximation thereof. The basic solution to compute the matrix operator is Moore-Penrose generalized inverse (GI) to derive this operator. There are two very useful properties of this DAM. First, when the key vector is incomplete, the recalled vector closet resembles the corresponding response data vector in a minimum squared error (MSE) sense. This situation occurs, e.g., when an object to be detected in an image is partly occluded by another object. Second, when the key vector is noisy the recalled vector is again optimal in the MSE sense. The recall can be viewed as the weighted sum of the response vectors. The recall begins by assigning weights according to how well the unknown stimulus vectors using a least squares classifier. The higher the weight, the better the association with the corresponding stimulus. The response vectors are then multiplied by the weights and added up to build the recall vector which is most closely associated with the unknown stimulus key vector. If the memorized stimulus vectors are dependent, then the vector recalled by one of the memorized stimulus vectors will contain the associated response vector and some crosstalk from the other stored response vectors. This report is trying to show that the DAM is in fact a regression problem. Regression analysis has been used previously for pattern recognition. The contribution of this correspondence is threefold. First, arguing that instead of using the weights directly for recognition, their t-statistics should be used extends the known method. Second, a method termed coefficient focusing is proposed to reduce crosstalk effects. The third in conjunction with the coefficient focusing method, the implementation of a reject option by using the coefficient of determination if discussed. The DMA method proposed by this report benefits from two major components which are the incorporation of a procedure to achieve insensitivity to geometric distortions and the focusing procedure which is used to decrease the crosstalk effects and enhance the selectivity of the weights. The performance of the methods was tested on images of wooden boards and it has been shown that it can in fact be used to recognize objects which are variable to a high degree. The reject option in the approach is relevant especially in cases where objects are imperfectly centered in the "receptive field" of the DAM, or where unknown objects must be identified. In this case the capability of the system to reject without a threshold was extremely low. This needs more study and improvement.

In 1993, Roberto Brunelli and his colleague Tomaso Poggio report the features versus templates on the face recognition[15]. They developed and implemented two new algorithms. The first one is based on the computation of a set of geometrical features, such as nose width and length, mouth position, and chin shape. This was the first approach toward an automated recognition of faces. A face can be recognized even when the details of the individual features (such as eyes, nose and mouth) are no longer resolved. The remaining information is, in a sense, purely geometrical and represents what is left as a very coarse resolution. The idea is to extract relative position and other parameters of distinctive features such as eyes, mouth, nose, and chin. These geometrical informations play a role when the mask stored in the database is used to locate the corresponding zone on the unknown image, whereas holistic information is taken into account by the pixel-by-pixel comparison of the correlation procedure. The second one is based on almost-gray-level template matching. In the simplest version of template matching, the image, which is represented as a bidimensional array of intensity values, is compared using a suitable metric (typically the Euclidean distance) with a single template representing the whole face. There are, of course, several, more sophisticated ways of performing template matching. For instance, the array of gray levels may be used to account for the recognition from different viewpoints. Still another important variation is to use, even for a single viewpoint, multiple templates. A face is stored then as a set of distinctive smaller templates. In the experiment used templates performed by the authors, the recognition is almost perfect. As a matter of fact, the template matching is superior in recognition performance based on the experiments carried out by this report. It is also simpler. The feature-based strategy, however, may allow a higher recognition speed and smaller memory requirements (information can be stored at one byte per feature, which requires only 35 bytes per person in the experiments). In summary, the reported correlation-based approach seems to offer satisfactory results for recognition from frontal views. However, a more difficult problem which is the reliable rejection of images of faces not contained in the data basis is failed to considered.

In order to obtain a signature of an object, which is independent of external factors such as the viewpoint, geometric invariants, which are shape descriptors remaining invariant under geometrical transformations such as projection or viewpoint change, become very important. A new method of obtaining local projective and affine invariants is developed and implemented for real images by Ehud Rivlin and Issac weiss, and reported in 1995[16]. In the reported paper, the projective (viewpoint) and affine invariants are treated in various geometrical configurations. There are two main kinds of invariants: global and local. Global invariants describe a shape as a whole so they require knowledge about the whole shape. Local invariants are defined at each point of a shape separately, which makes them less sensitive to occlusion. Recognition can be done through an invariant "signature" of the shape. For instance, in the Euclidean case, it is common to plot the curvature against the arc length, both of which are local Euclidean invariants. Such plots or "signatures" of curves can then be matched even if part of a curve is missing due to occlusion. In the research, no search is involved. The signatures were obtained in the projective and affine cases. One can build an object recognition that uses invariant signatures of curves, rather than the curves themselves, for storage in a visual database and matching. Because of the invariance, the matching doesn't require a search for the correct point of view. This is possible because of a general property that determines the uniqueness and completeness of the invariants. The method of deriving the needed invariants consists of defining a canonical coordinate system by the intrinsic properties of the shape, independently of the given coordinate system. Since this canonical system is independent of the original one, it is invariant and all quantities defined in it are invariant. The canonical method is general and can be used locally or globally, implicitly or explicitly. They used the implicit curve representation since it enabled us to avoid fitting errors associated with the curved parameter. The developed method has been applied to find local invariants of a general curve without any correspondence and curves with known correspondences of one or two feature points or lines. The experimental results for both cases show that by using the local implicit method the invariant signature can be found which is both insensitive to occlusion and relatively reliable. The only drawback is that the method for obtaining the invariants is highly computational expensive.

Along with the fast development with computer graphic analysis skill, more and more approaches towards the face recognition come into existence. 1996 Francois Goudail etc. used autocorrelations and multiscale integration also achieved the recognition of facial features[17]. The report presented by this group is emphasized on linear discriminate analysis in combination with contrast-based rejection criteria and multiresolution integration. Autocorrelation coefficients are computational inexpensive, inherently shift-invariant and quite robust against changes in facial expression. An experiment is developed to investigate the performance of the used technique for the face recognition based on the computation of 25 local autocorrelation coefficients. Using a large database of 11,600 frontal facial images of 116 persons, a thorough statistical evaluation of the approach is conducted. A simple, yet effective rejection criterion decreased the false access rates by about one order of magnitude. The introduction of a computationally efficient modular multiresolution architecture allowed to reduce the false access even further, from 15% to 1.5%, while achieving a recognition rate of 95%. The system error dropped from 8.5% to 2.74%. Information integration from multiple sources is essential for reliable performing difficult classification tasks. In this approach only a relative low computational effort involved in both learning and the recognition process of the system makes it very fast. The implementation of a segmentation module based on template matching, which will allow robust image segmentation and also give additional clues for classification is not yet implemented.

A face recognition system must recognize a face from a novel image despite the variations between images of the same face. Images taken for the same face often varies in the illumination conditions when images are being taken. The common approach to overcoming image variation of changes in the illumination conditions is to use image representations that are relatively insensitive to these variations. Examples of such representations are edge maps, image intensity derivatives, and image convolved with 2D Gabor-like filters. In the past, three main approaches for dealing with images variations that are due to illumination changes have been used. These approaches are used by general object recognition systems as well as by systems that are specific to faces. The first approach uses the gray-level information to extract the three-dimensional shape of the object, namely, a shape from shading approach. This is an ill-posed problem and, therefore, all proposed solutions assume either the object shape and reflectance properties or the illumination conditions. These assumptions are too strict for general object recognition, and therefore were not shown to be sufficient for the face recognition task. The second approach to handle image variations that are due to illumination differences is by using as a model several images of the same object (face) taken under different illumination conditions. The images can be used either as independent models or combined into a model-based recognition system. The third approach, which is a new approach by Yael Adini etc.[18], reported in 1997, takes a different view of the problem, which evaluates the sensitivity of the representations including edge maps, image intensity derivatives, and image convolved with 2D Gabor-like filters, to changes in illumination as well as viewpoint and facial expression. The reported study examined several popular image representations, computed by local operators, and often considered relatively insensitive to illumination changes applied to face images. These include images filtered with 2D Gabor-like functions, directional and nondirectional derivatives of Gaussian filters, and edge maps. In order to answer to what an extent these types of image representations are sufficient by themselves to overcome image variations, this research group constructed a database of faces in which the face identity, illumination, viewpoint, and expression were controlled separately. The actual distances between pairs of images of a given face (or image representations) of different faces were computed and compared with the variation between pairs of images that vary because of a change illumination, viewpoint, or expression. As a preliminary study, some smaller variations between light source location and left vs. center (instead of left vs. right) were examined. The result shows that for the best representations found, the miss-percent was reduced to eight percent. The failure reported to be small. The better result is expected when more limited variations between images of the same face are considered. From the above discussion, we can see that the restriction on the images that can be processed by this technique limits the wide application.

An analytic-to-holistic approach[19] for face recognition based on a single frontal view is reported by Kin-Man Lam in 1998. In this approach, they first use a new analytic method to select similar faces from a database. The positions of the different facial features and their outlines are located. A total of 15 feature points are chosen according to their significance, and the reliability of the detection. A head model is built in such a way that the rotation of the face can be estimated by geometrical measurements. The feature points are adjusted to compensate for the effect of perspective variations. Only the similar faces in the database will considered in the next step of face recognition. Correlation of the eyes, nose and mouth are computed in the second step. These two parts are combined to form a complete face recognition system, which can achieve a high recognition rate under different perspective variations. Based on the feature points, a similarity transform and point-matching for face recognition is proposed. Only those faces in the database similar to the input face are considered for the next step, which considers the geometrical distortion caused by head rotation. In the report, both the individual performance of the two steps and the combined performance are investigated. There are two methods presented for face recognition. The first method is based on the information concerning where the facial features are. The 15 feature points are used to represent a face. The positions of these points are adjusted according to the angles of rotation. The point set for an input face is then compared with the point sets of the faces in a database by point-matching. Faces similar to the input are chosen from the database and passed on for the second recognition process which measures the difference in context for the different facial features between the input and the database. Three windows, namely, the eyes and eye-brows window, the nose window, and the mouth window are established for each face. The overall performance, by combining the point-matching method and correlation is investigated. Using the automatic selection procedure, recognition rates of over 84 percent and 96 percent are obtained for considering the first and the first three likely matched faces, respectively. The corresponding recognition rates achieved using the manual selection procedure are over 89 percent and 97 percent, respectively. The overall performance of the system suggests that the different feature-based approaches and the holistic approaches may be combined, which will provide a much higher performance level than that of any individual approach. Since every image needs 15 features and a database also needs a considerably large number of images, the process time for the recognition is rather lengthy and needs to be improved.

After a few years hard working and plenty experiments on facing recognition system, Ian Craw etc. reported their new technology, eigenface coding[20] also in 1998, which is more effective than coding technology of shaped faces. In this approach, the main concern is to contrast simple image-based codings with subspace codings, particularly eigenface codings, derived from Principal Component Analysis (PCA) and to investigate the effects of content-based preprocessing on these methods. Eigenface codings were used to demonstrate pattern completion in a net-based context, for representing faces economically, and explicitly for recognition. This report has explored the utility of a form of subspace coding which involves significant content-based preprocessing, dependent on the identification of the objects to be represented as belonging to a particular class. Thus, the subspace is not spanned by real images, but rather by distorted versions (shape-free faces) chosen for their expressive power in terms of intraclass discrimination. The coding was derived from abstract mathematical principles and, in particular, a consideration of the appropriate structures to express the invariances needed for recognition purpose. This led to a manifold-based model of "face space" in which configuration and textural information are separated. Although of interest theoretically, the report has discussed it purely in terms of effectiveness, comparing the performance on a fixed set of recognition tests with other codings. The main result from the report, that the shape-free transformation gives improved coding for recognition, is valid in this context, but a further improvement comes from adopting a preferred basis of shape-free eigenfaces for the face subspace, namely, that obtained by using PCA. The traditional advantage of PCA, allowing a maximally expressive truncated representation, only holds for images in the ensemble and this is of no direct concern. However, the variances associated with eigenfaces allow the use of Mahalanobis distance in matching, which does give a worthwhile improvement in recognition rate. The clear advantage for Mahalanobis distance over Euclidean distance, consist across conditions, provides evidence that PCA is a more appropriate method of coding faces than simply using raw images; and that something more sophisticated than simple template matching is occurring. Overall, this research report has shown that coding using PCA, implemented under the influence of a manifold model of "face space", separating configural and textural information, has proven to be of value for recognition, and that this could be of relevance when constructing psychological models of face recognition. However, the very high levels of recognition by shape-free contour matching and then increase in recognition when this is combined with the shape-and-texture output show that not all the facial information has been captured.

Same year in 1998, Neural Network-based face detection technology[21] also reported come into existence. It was reported by Henry A. Rowley and his team members. In this report they present a neural network-based algorithm to detect upright, frontal views of faces in gray scale images. The algorithm works by applying one or more neural networks directly to portions of the input image and arbitrating their results. Each network is trained to output the presence or absence of a face. The algorithms and training methods are designed to be general, with little customization for faces. For the neural network recognition development, the training for the face detection is challenging because of the difficulty in characterizing prototypical “nonface” images. It is easy to get a representative sample of images which contain faces, but much harder to get a representative sample of those which do not. This problem is avoided in this report by selectively adding images to the training set as training progress. The “bootstrap” method reduces the size of the training set needed. This algorithm can detect between 77.9 percent and 90.3 percent of faces in a set of 130 test images, with an acceptable number of false detection. Depending on the application, the system can be made more or less conservative by varying the arbitration heuristics or thresholds used. The system has been tested on a wide variety of images, with many faces and unconstrained backgrounds. A fast version of the system can process a 320X240 pixel images in two to four seconds on a 200MHz R4400 SGI Indigo2. But the main limitation on the system is that it only detects upright faces looking at the camera. Separate versions of the system should be trained for each head orientation, and the results should be combined using arbitration methods similar to the reported one.

The last approach on face recognition will be introduced here is face detection from color images using a fuzzy pattern matching method[22] which was reported by Haiyuan Wu in 1999. Among many reported studies on automatic face recognition, most of them concentrate on quasi-frontal view faces. This is because the prior knowledge of the geometric relation wit regard to the facial topology of frontal view faces can help the detection of facial features and it also makes the face modeling with a generic pattern possible. However, the quasi-frontal view assumption limits the kind of faces that can be processed. A representative paradigm detects faces with two steps: (a) locating the face region or assuming that the location of the face part is known and (b) detecting the facial features in the face region based on edge detection, image segmentation, and template matching or active contour techniques. One disadvantage of step 1 is that the face location algorithm is not powerful enough to find out all possible face regions while remaining the false positive rates to be low. Another disadvantage is that the facial-feature-based approaches rely on the performance of feature detectors. For small faces or low quality images, the proposed feature detectors are not likely to perform well. This reported paper describes a new face detection algorithm that can detect faces with different sizes and various poses from both indoor and outdoor scenes. The goal of this research is to detect all regions that may contain faces while remaining a low false positive output rate. The researchers in this report first develop a powerful skin color detector based on color analysis and the fuzzy theory, whose performance is much better than the existing skin region detectors. A hair color detector, which makes possible the use of the hair part as well as the skin part in face detection has also been developed. The head-shape models to cope with the variation of the head pose are also built. After building all the models, the fuzzy theory based on pattern-matching technique is used to detect face candidates by finding out patterns similar to the prebuilt head-shape models from the extracted skin and hair regions. This fuzzy pattern matching method makes possible the pattern detection using a pattern description model carrying different kinds of information from the input image. It gives the flexibility in designing the head-shape model. After implementing this algorithm, an experiment has been carried out to test the system. Seven image-sequences (five men and two women) were used to build the head-shape models. The result shows that this approach, skin color detection, compared with other existing methods is much more accurate and efficient. The multiple head pose models allow us to detect faces of various poses. This approach is also not sensitive to small changes in the face which can be considered as robust. And compared with neural network approach this method is much faster and performance is good too. While these attractive aspects of the approach look charming, the failure often happens from this system. The reasons for the failures occurred in the experiments under concerns include the following: (1) illumination: because the color is used to detect the skin part and the hair part of faces, the variance of the illumination color will affect the detection result.(2) occlusion: if a face is largely occluded, the cells in head-shape models corresponding to the occluded part of the face will give low output, thus the total matching degree may not be high enough to let the face be detected. (3) adjacent faces: if two or more faces are too close, the skin parts or hair parts of them may be merged together. The shape of the resulting skin-hair pattern may be very different from the one for a single face. (4)Hairstyle: faces with special hairstyles, such as skinhead, or wearing a hat, may fail to be detected. This is because the shape of the skin-hair pattern of such a face in the image may become quite different from our head-shape model. This method may also give some false positives under some conditions. The reason for this is because in the method only the shape of the skin-hair pattern is used and all the details about facial features during the face detection are ignored. Due to these imperfections of the system, the images that can be processed are actually limited. One is forced to take a picture under some strict rules. Of course this is not realistic all the time in the real life.

From the above review on face recognition we realized that even extensive effort has been put into this field but due to either the extremely expensive computation or being sensitive to image noises, head-pose and complex background, more research still need to be done. And the accuracy, efficiency and expense should be the next goal.

3. Our research work

Above all of the discussion and review above, we have done some research both on restoration of degraded images and object similarity detection and obtained some valuable references for the researchers in the fields.

- Restoration of Degraded Images

Our approach to restoration of degraded images is simple and efficient, especially for salt and pepper noises. The main idea is to detect a salt or pepper noise pixel whose pixel value should be dramatically different from its 4-neighbor pixels and replace its value by the mean value of its 4-neighbor. The program will carry on the iterations to scan and smooth the whole image until no more singularities are found in the target image. Of course this algorithm is only good for images that have clear edges and sharp changes between objects.

- Similarity Measure Between Objects

Our initial motivation for the detection of similarities between two images is from the research that is using 2D histogram for image segmentation conducted in MIT. The basic idea is that if two images are identical, the resultant 2D-histogram image should only contain a straight line with 45^0 slope. If two images have great similarities, the resultant 2D-histogram image will have some clustered areas. For two irrelevant or rather different images, the resultant 2D-histogram image would be a uniform intensity distribution with no particular patterns generated. For the geometrical similarities the edge 2D-histogram image should do the job. After a few months' researches and experiments on this approach, we finally realized that there is a fatal limitation on the application of this algorithm, which will be discussed in chapter II.

- Image Processing Interface

For enhancing this image-processing research, an interface that has a small database of images and allows users to do all the basic functions of image processing, such as Guassian Smooth, Canny Edge Detector, Linear Edge Detection, Gray image, displays a Gray histogram, 2D-histogram image, 2D-edge histogram, two histograms' difference, and the 2D-histogram graph (use one histogram as x-axis and the other as y-axis), and some search task, such as search under names, key words, histogram, edge, top region in an image, top edge lines etc.

- Structure of this report

In chapter I we introduce the research on the noise removal and the experiment results. Chapter II is for the study on the 2D histogram of two images to be used for detection of similarities of objects, which is also the main research work of this project. In this chapter we start with the development of the idea, exploring of its extension, extensive experiments, exploration of its potential application and full realization of this approach. Chapter III is the introduction to the image-processing interface that has been built for helping with the research work. This interface has been used intensively during the whole project period and has supplied a great convenience on the research work. A detailed description on the functionality embedded in the interface is also provided in this chapter for any future reuse of the interface.

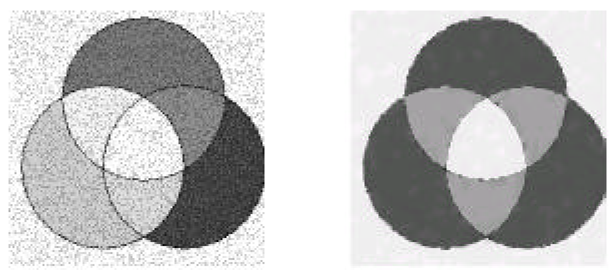
All the implementation of this project work is written in Jave Language and compiled by JDK1.2. The complete source code is also attached at the end of this report.

Chapter I Restoration of degraded digital images

As everybody in image processing field knows, the research on restoration of degraded digital images is active and has attracted a lot of attentions. The essence of our approach to restoration is simple and efficiency. It is also the first step for image segmentation. Our approach is only focused on dealing with salt and pepper noises on clear objects images.

Salt and Pepper noises, just like the names, are single white or black pixels embedded in an image. To detect this kind of noises we need to compare the current pixel value with its 4-neighbor pixel values. If a pixel value is greatly less or greater than all its 4-neighbor pixel values, which would be the simplest case, we immediately know that we have found a noise. If the current pixel is on the boundary of the image, we would be facing the difficulty in comparing its value with all its 4-neighbor pixels. For this case, we need to build a guard to the image to guarantee we would not go over the boundary. To advance one more step, we are able to detect single line noises, which often exists in life images. To capture line noise only compare a pixel with its 4-neighbor is not enough. When we detect a pixel has only one friend in its 4-neighbor (similar intensity value), we need to carry out more comparisons which are between the current pixel and its 8-neghbor to finally determine its property. After we have definitely detect a noise pixel we use the mean value of its 4-neighbor to replace its pixel value to remove the noise. For non-noise pixels we also do a little smoothing which is to replace a normal pixel value by the mean value of its 4-neighbor and itself. The program will iterate on this process until it sees the change every run makes is less than a preset threshold it will terminate automatically. The disadvantage of this approach is that we will lose some details in the resultant image, which turns out has no crucial effects on later segmentation operation. Therefore this disadvantage is tolerable.

Figure 1 is the degraded image (a) and the image (b) after noise removal for comparison. Only 5 iterations were needed on this process.



(a) (b)

Figure 1 (a) Original degraded image, (b) Resultant image after noise removal

Our experiments have shown that our approach is simple and efficient for the simple noise removal purpose.

Chapter II The approach of 2D-histogram Image to similarity detection between images

Accurate detection on similarities between images could have significant application in a large amount areas. One of them could be criminal facial analysis. Even distinguishing differences between people's faces is extremely easy for human beings, it has been a great challenge for computer systems to do a similar and accurate job. A great effort and research has been drawn to this field for years.

The approach we had was intrigued by MIT's 2D-histogram algorithm, which was initially used on the separation of objects from their backgrounds. The idea of this algorithm is to form a 2D-histogram image from two target images. For similarity detection we were focused on the properties the resultant 2D-histogram image possesses. But after an extensive study and broad experiments done on this approach we come to realization that this charming approach actually has a potential limitation on its applications. The detailed analysis and results of experiments are presented in the following.

- **First Hope**

  For two identical images, the 2D-histogram image would be an image of a straight line with a 45^0 slope. This would easily be the starting point of the trial of this approach, which is also easily understood and proved both theoretically and experimentally. Figure 2 is two identical images (we only need to show one here) and its resultant 2D-histogram image.

After this step we would start to think that for an image with a certain kind gray histogram distribution, the clustered pixels within the peak of the histogram should form clustered areas in the 2D-histogram image. So this would be the key of this approach, which means if the resultant 2D-histogram image of the two images has some clustered areas or simply patterns we would have the hint that these two images have great similarities. The measure of the similarities could be a percentage of the pixels within these clustered areas. Since we had a few clear sharp images at hand at that time, we experimented with them and we were very happy to see the proof from the results.

- **First Failure**

We went on. What about we just rotate an image then compare with its original? We asked ourselves. We thought about the edge 2D-histogram, since an edge image would contain the critical information about the geometric of an image. So we tried the edge 2D-histogram images for some amount of images. The problem started to come in. First the resultant edge 2D-histogram image is very faint. We built some extra functions to strengthen the resulted image. Second, after strengthen the resultant image, we saw that most of the pixels were used to form a square with typical size of 50 by 50. The result was thought as a programmatic mistake initially. After more experiments on different images, even on identical images, similar patterns were generated from each time. We started to think the real reason that was behind. We realized that canny edge detector, which is normally considered as an good and accurate edge detector, had failed our expectation on this task, since the most of resultant edge pixel values are either greater than 250 (non edge) or below 50 (edge). These pixels would only form four boundary lines and a small faint pattern of 50 x 50. This could fully explain the strange images we had got from the edge 2D-histogram. For linear edge detector that basically takes the derivatives of neighbor pixels, since the differences between most pixels within an object in an image are small, it will also only generate an image with a small and rather scattered pattern and hard to contain any crucial information we need. After this, the idea of edge 2D-histogram image was discarded.

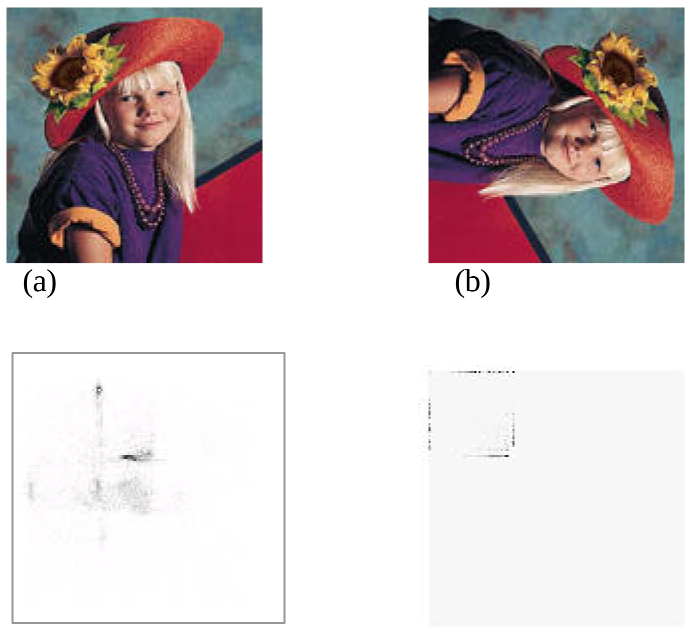
- **Full Realization**

We continued the experiments with 2D-histogram approach. When more images were involved we started to get something that we didn't expect, which for some very similar images we didn't get clustered blocks in the resultant 2D-histogram image. After the confirmation for this not being any mistakes in the program, we realized the critical drawback for this approach. The problem is that for images with rather uniform gray histograms, no matter whether there are great similarities between images or completely irrelevant to each other, the resultant image would be a uniform distribution of pixels. The study on the images of human beings' faces shows that the gray histograms for human beings' faces are rather flat. This has announced the basic failure of this approach for most of its potential application even we could say there are still applications of this research but that would be narrow and limited.

Even though, the experiments and results can be a good reference for some research. I post the basic results and the images here. (Figure 3, 4, and 5)

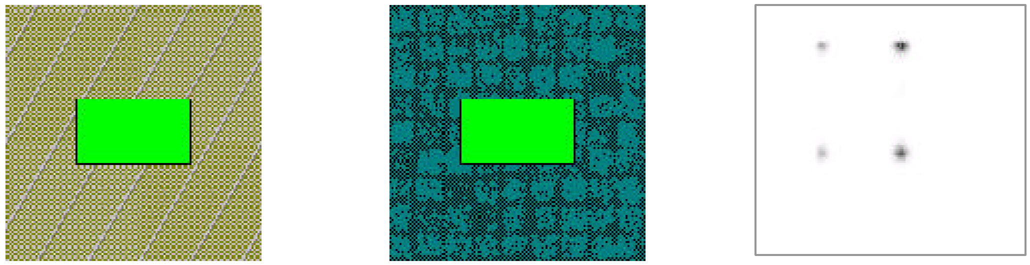
(a) (b)

Figure 2. (a) Original identical images (b) the resultant 2D-histogram image



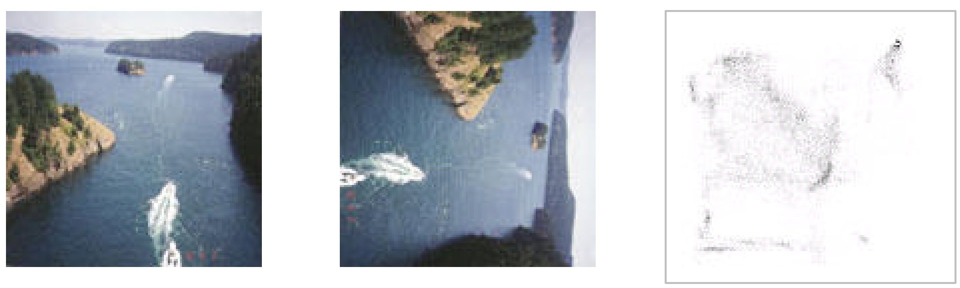
© (d)

Figure 3. Images used here have non-uniform gray histogram. We see clustered pixels in © and a small resultant square in (d). (a) Image 1, (b) image 2, (c) 2D-histogram image, (d) 2D edge histogram image



(a) (b) (c)

Figure 4. Same object in different texture backgrounds and their 2D-histogram image. We see obvious clustered areas. (a) image 1, (b) image 2, (c) 2D-histogram image.



(a) (b) (c)

Figure 5. Images with rather uniform gray histogram and their 2D-histogram. Here we have two same images besides the rotation, but the 2D-histogram shows no clue of the similarities. This is the real failure.
(a) Image1, (b) Image 2, (c) 2D-histogram Image.

Chapter III Introduction to the image-processing interface

For the research convenience, an interface that has most of the basic image-processing functions was built. Figure 6 shows the interface and all its available functions (printed on the button).

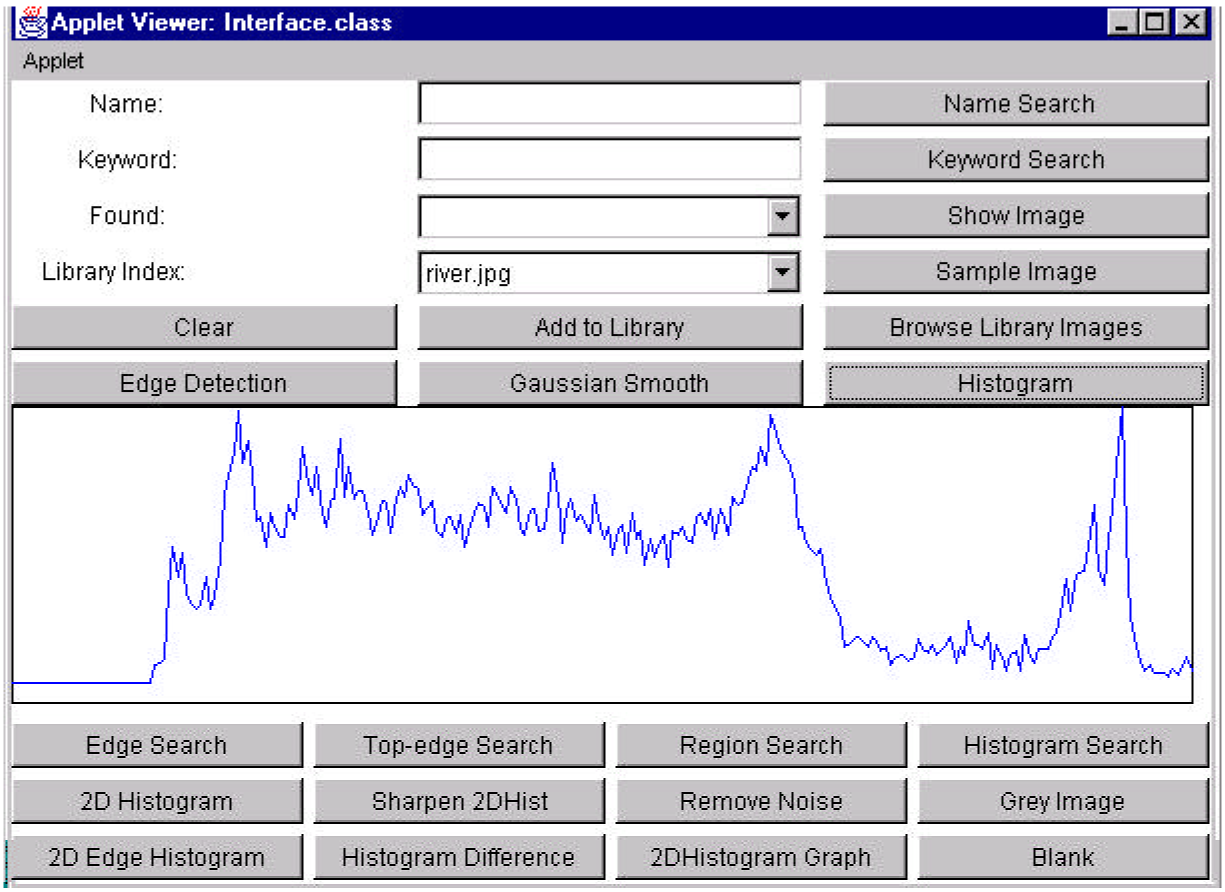


Figure 6. Designed interface.

The functionality of this interface that allows user to interact with the interface is described as the followings:

- Browse Library Images Button:

  Allows a user to browse the images in the library page by page. On each displayed image page, information includes how many more images left in the library and the file name of this displayed image is displayed with the image. There are two buttons labeled as "next" and "back" allow users to go back and forth to browse images in the database.

- Name Search and Keywords Search:

  Allow users to type in some information about a particular image, such as name and key word to search through the library. Searching functions, both name and keyword, allow users to use wild characters. The search result will be display in the found field. If there is only one image found during a search then only one image's file name will be displayed, otherwise a list of images will be listed. If no image in the library matches a search then 'not found' will be displayed. If a user type in '*' or '*.*' in name or keywords search field and go search, all the images in the library will be displayed in the found field which is what we expected to happen.

- Show Image Button:

  If there is something in the found field then 'Show Image' button will display the selected image in the found field. If found field is empty then the selected image in the library index will be displayed.

- Edge Detection Button:

  After an image is displayed by using show image or sample image button, users can click on this button to display the resultant image after applying canny edge detector algorithm.

- Gaussian Smoothing Button:

  Allows users to view a image after applying Gaussian filter. The Gaussian filter is used in this program is 3x3 filter.

- Histogram Button:

  The gray scaled histogram curve of the displayed image will be displayed on the interface empty panel (center).

- Sample Image Button:

  Users can choose an image from the pre-registered images in the database as a sample image. A series of image processing functions can be applied. A search based on a feature of an image is similarity search. The search will search for images that have the feature difference under a threshold. But the names and keywords' search are the exact search.

- Edge Search Button:

  Searches for images in the library that have similar edge percentage of whole image.

- Top-Edge Search Button:

  Every image has a set of indices are pre-stored in the program. One of these indices is the first three longest edge line. This button based on the three longest edge lines of the current image to search for images that have similar length of these three lines in the library.

- Region Search Button:

  Searches for the first region in an image and compares with the sample image.

- Histogram Search Button:

  Each image in the library has its grayscale histogram and color histogram. Color histogram of each image has been quantized into 16 bins for each color of RGB. This information is stored in the library. Base on the sample image's color histogram we can search out all images in the library that have similar color histogram.

- Add to Library Button:

  As users' wish, by typing in an image file's name and keywords in corresponding field, a user can add this particular image into library. A new added image feature (edge information, histogram, region etc) will be calculated and stored in the library.

- 2D Histogram Button:

  Users can chose any two images in the database to be the sample images and display their 2D-histogram image.

- Sharpen 2Dhist Button:

  It often happens that the displayed 2D-histogram image or 2D edge histogram image is not clear, then this button can strengthen pixel intensities and display it clearly.

- Remove Noise Button:

  Removes the salt, pepper and line noise on the displayed image and displays the resultant image.

- Grey Image Button:

All images registered in the database are color images. This button is to display the gray image of the chosen image.

- 2D Edge Histogram:

  After a user has chosen two interested images, this button with first get the edge images for both target images then form the 2D histogram image of the two edge images and displays it.

- Histogram Difference:

  Display the one dimension gray histogram difference for any two target images.

- 2D Histogram Graph:

  Take one image's histogram as x-axis and the other as y-axis and displays the 2D graph in the panel in the middle of the interface.

There are a few images are pre-registered in the library when the program runs. Users can add in as many images as wish. All the images should be in either jpg or gif format and with size of 128X128. The reason for the size limit is due to the long computing time. If one wishes to add in any size of images, changing one line code can easily do it.

If users wish to put more images into library offline, the file 'data.txt', which contains the basic information about images in the library, can be modified easily. Users should allow the program to have about one minute or so based on the computer speed to load all the information and images in the library when the program just starts.

This interface has helped a great deal in the whole time of the project conducting. Especially when a lot experiments with images need to be done.

Chapter IV Conclusions

This thesis is focused on the restoration of distorted images by salt and pepper noises and similarity measure between images. Using mean value to replace the noisy pixel value has been proved to be an efficient way for salt, pepper and thin line noise removal. Normal procedure for noise removal by using the reported algorithm only requires 5 or less runs. Efficiency is the main achievement for this algorithm. 2D histogram is proposed as an informative way to detect the similarities between images. The research starts from sketch and goes through all the steps to prove the theory. Detailed discussions on all steps are provided. The result from each step is discussed and provided too.

This research work has been a very helpful experience for a student to use what has learned in class and textbook to the real life project.

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