Medical Imaging Based Computer Aided Diagnosis

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Abstract : Medical Imaging based Computer Aided Diagnosis (MICAD) integrates image information from
different medical imaging modalities into a new image, which is dynamically performed for serial analysis of the
images for a patient. The most important direction is the addition of the functional information into anatomic
images, because the functional information supplies the more physiological information to tell the difference
between normal tissue and lesions. This method is helpful for making the correct decision for patients during
clinical diagnosis and treatment. The procedure of MICAD includes the data acquisition, the noise reduction, as
well as the basic imaging process and analysis, such as the image segmentation, the image registration, the image
fusion, the pattern recognition and the image display. The essential methods and the prospect of MICAD were
introduced in this paper as well as the brief introduction of MICAD in China.

Key words : medical imaging based computer aided diagnosis, imaging process, imaging analysis

1. Introduction

With the efforts of the scientists from cross-disciplinary of the medical physics and the medical
informatics, a large number of images obtained from different medical imaging instrument are used in clinical
diagnosis and varies therapies everyday. Reading the huge amount of the images is a rather hard work for
radiologists in clinical cases. In order to reduce the working capacity of reading the images and increase the
accuracy rate of the clinical diagnosis, a new technology named as medical imaging based computer aided
diagnosis (MICAD) was developed rapidly in the world in recent 10 years.

The problems existed in the field are as following: first, the physicians in hospitals have to take much time
to read all these images everyday; second, a single image is not enough to provide suitable information for
the correct diagnosis. At present time in the world, the diagnostic accuracy rate with images is about 85% in
average, instead of the 50% in the case without images. Misdiagnosis is still unavoidable. Moreover, the
diagnosis accuracy is dependent on the experience and capability of individual physician. Therefore, MICAD
has the potential market in clinical diagnosis now and will have bright future.

It is emphasized that based on the progress of medical imaging, more and more functional imaging
information produced, which does not directly show the lessons in images, but the information is very useful both
for diagnosis and treatment. In order to dig out the regulation expressed by physiological or psychological
parameters derived from functional imaging, we have to do a lot of calculations based on various models to
describe functional parameters.

Because biological meaning of each image from different modalities is quite different, the appearance and
the features of the images are also different, which makes
the diagnosis process become very complex. This situation is also dependent on individual patient. Furthermore, the same disease may have different morphological structures, while similar morphological structure shown in an image could represent different disease. Only morphological information is not enough to determine individual disease for a patient in its earlier state, and even more difficult to determine the level of disease in the disease development circle. From the view of science, the information of a human can be divided into three fields: morphology, physiology and psychology. All of them can be imaged by the modern medical imaging facilities. But it is impossible to integrate the information in all three fields simultaneously with only one kind of imaging modality. Therefore, how to integrate all imaging modalities together and solve these problems described above is the essential task of MICAD. High quality software of MICAD should be able to change the diagnosis scheme and the treatment routing from different requirement of clinical tasks. Therefore, the MICAD technology can save the time and reduce the cost for health care. MICAD supplies different options and tools to increase the diagnosis accuracy, and provide more information of the disease. However, MICAD is only an aided tool in clinical. The final decision should be made by clinical physicians, because the computer is still not intelligent enough to make the correct clinical decisions. Then the main purpose of this technology can be summarized as following:

1. Based on mass data of patient images, MICAD can help physicians to find out the foci used for further analysis in the diagnosis process to avoid the leaking diagnosis;

2. Based on the analysis of large number of imaging data, MICAD can integrate the information of a special disease for its correct diagnosis or treatment;

3. Identify these realistic foci from the integrated images to increase the diagnosis and treatment accuracy rate by the methods of reducing confused foci in the images.

The procedure of MICAD includes following main steps: imaging data acquisition, imaging data preprocessing, such as image segmentation, registration, and image fusion, as well as the key step of the MICAD: pattern recognition and classification. Among them, the image segmentation, registration, fusion and pattern recognition are important technologies and are still on the way to be developed in the field. All these technologies will be discussed in some detail in the following sections. More detail information can be found from reference [1, 2]. The procedure of the scheme is shown in Fig. 1.

The golden standard of MICAD is the knowledge of pathological truth by histological check with biopsy.

2. The main technologies used in MICAD

2.1 Data Acquisition

If people want to use the technology of MICAD, they have to acquire the data using medical imaging equipment with high spatial resolution during annually health check. One of these examples is the annual check of breast cancer for women during their ages from 35 to 55 years old, which was set up in United States as a regulation with normal screen-film X-ray planer imaging

![Diagram of MICAD process](image)

**Fig. 1** Scheme of MICAD
Fig. 2 Geometries of data acquisitions for breast check using planer X-ray imager in (a) vertical direction; (b) declining direction.

The data acquisition for breast with two geometric structures is shown in Fig. 2. Different imagers and different organs have their own problems for data acquisition process. But basic principle is that the spatial resolution should be high enough for finding the suspicious foci and cover the full volume of the organ with these foci.

If the data acquired are not in digital form, then the digital processing is necessary with the equipment such as laser derived film-digitized system. The key problem is that the image resolution and contrast should not be worse, at least it should not be degraded too much.

2.2 Preprocessing of images

After the data acquisition, the data should be reconstructed if the MICAD is based on 3D medical images. Noise always exists in images, therefore, noises have to be reduced for the deform artifacts, which are caused by the system uncertainty of imaging facilities or the unavoidable statistical noise by various methods including the most often used smoothing method [5, 6]. Then people need to build a coordinate system to make these images be described at same frame of the coordinate.

2.3 Image segmentation

Image segmentation can be divided into different levels and be used in different stages of the process routine.

The first stage of the segmentation is to limit the regions to be analyzed from an interested organ or corresponding part of human body just after the data acquisition, which makes the analysis faster and more efficiency for a specific disease in a specific region. Therefore, this segmentation is called the edge extraction. Any methods used for pick-up the edges of images can be used here.

The second stage in the segmentation process should be done just after the three dimensional coordinate system has been built up, which divide all possible suspicious foci in the serial of these images. For instance, pointing out the suspecting tumor foci before formal analysis procedure of MICAD.

The last stage in the segmentation is an analysis process rather than only a segmentation process itself, which determine the truth foci via the classification process with four situations including true positive, false positive, true negative or false negative for all these suspicious foci. Therefore, this step should be done after the pattern recognition or feature extraction of all

Fig. 3 Results got from KNN algorithm. First row: skin and muscle; the skull and fatness; Second row: grey matter, white matter and cerebral spinal fluid.
potential foci. Some more details of the pattern recognition or feature extraction are described in section 2.6. In this step, the functional information is very important for correct cognition and classification because these parameters are sensitive to normal tissue and lesions.

The methods used in our group for edge extraction can be found in [7, 8], and the methods for tissue segmentation or focus segmentation used in our group named as the k Nearest Neighbor (kNN) and the fuzzy nearest prototype (FNP) can be found in [9]. By the combination of the feature and the anatomic knowledge of the MR images, a set of neighborhood rules were established and some examples were shown in Fig. 3 [9].

2.4 Registration

The task of the registration is to obtain their accurate matching for further treatment. This procedure is very important and is often used in clinical case that the images of a real object has been divided into many slices, which needs to be put together for understanding the imaged object, especially for the information concerning with the knowledge of the suspicious foci, including the functional information in the positioning process. It is difficulty for the registration procedure mainly because of the differences between images from different imaging modalities with different spatial resolution, different noise level and the different parameters used to describe the imaging. Therefore the essential tasks of registration are as following:

Arrange images from time serial slices and match them for the correction of the body movement during data acquisition if motion artifact exists;

Register these images in the region of interested (ROI) for the corresponding images from same patient using different imaging modalities, or for the corresponding images from same imaging modality in different time;

Register the suspicious foci at levels of ROI. The results will be used for next procedure of MICAD.

The registration criteria are the maximum similarity between the original image and the image to be registered based on voxels in ROI. The cross information usually come from the features described in the images for the disease, e.g. the grey information, the gradient of the grey intensity, and the direction of the gradient. All should be continuous in neighboring voxels. Therefore, this is an optimization process of similarity search, the criteria for such search are usually supplied by physicians according to their experience.

The research on the image registration in our group includes the edge extraction in Fourier space [7], and the singular value decomposition and iterative closest points (SVD-ICP), which is actually an appropriate solution for the point matching problem of n-dimension space [10]. Both of these methods can well deal with the problems of edge extraction and the matching in multiple dimensional spaces.

2.5 Image fusion

The medical imaging fusion plays as an important role in information integration, which integrates the information from different imaging modalities into a new image for easy understanding of the foci and for more accurate diagnosis in segmented region. This process should be done after registration. The main question that the fusion process should answer is how much information should be taken from the original images of different modalities to satisfy the diagnosis. The answer is not easy because there is no general regulation for such selection. And any diseases have their individual features, which in some degree depend on individual patient. Therefore, the task is how to generalize the regulation for a certain disease. In this case, the experience of clinical physicians is very helpful.

The imaging fusion could be done with multi-pattern imaging data, e.g. the images from PET, X-CT, MRI, and fMRI of a same patient, which will be integrated into a new image in the fusion process. The essential fusion principle is the “pattern saving”, which
means saving the key features you could read from each original image. These key features should be continued with their morphological and pathological salient features in the new image for a specific disease.

There are two kinds of fusion methods: one is the fusion directly based on the voxel domain, another is the fusion based on the transform domain. Modern fusion methods are usually extended from the image encoding and the compression technique based on the transform domain, such as the Laplacian pyramid method, the sub-band coding technique and the sub-wave transformation.

The method of medical imaging fusion process was also developed in our group. The method we used was the wavelet decomposition [11], which was based on the principle that the human visual system has the different sensitivity for the features in different scales. Therefore, the multi-resolution analysis was necessary for the fusion process. During the process, we managed to preserve all the salient features in source images and avoid any new artifacts or any inconsistency which would distract the observer and affect following processing stages. Wavelet based fusion scheme satisfies the requirement quite well due to lots of advantages of the wavelet transformation technologies. The decomposition and reconstruction of wavelet pyramid of source images were based on Mallat’s theories [13]. The most important step for fusion was the formation of fusion pyramid. In fact, different occasions emphasize the different salient features, so it’s difficult to generate an uniform standard for fusion principle as described before. Hence we provided more selection rules for users to satisfy various applications. Particularly, we applied the concept of feature salience parameters and feature similarity parameters for different ranges in every high-pass level of pyramids [14].

With this method and corresponding software developed in our group, the fusion between the images of X-ray CT, MRI and PET were performed for head image. Since the contours of the head of CT, MRI and PET images were similar each other, we took them as the objects to be registered. The difficulty lied in the segmentation of brain image of MRI. Some linkage between brain and other tissues was not so easily to be removed by automatic methods. Therefore, a semi-automatic segmentation method was developed, which ensured the extracted contour correct. Furthermore, in order to acquire a tradeoff between the speed and accuracy for iteration, we sampled the contour points based on the salience feature decided by the local curvature. An example of the fusion result was shown in Fig. 4.

2.6 Pattern recognition

The main task of image pattern recognition is to pick up the image features of a certain disease for identification and classification, which is actually an imaging analysis process. Only when one knows the features of the disease derived from many clinical physicians, it can be modeled with mathematical formula or physical models. Cooperated with the experienced physicians, we can get these image features through the pattern recognition process that were already treated by
the process of registration, segmentation or fusion. The main features for pattern recognition include three kinds of parameters: intensity parameters, physical parameters and functional parameters. The intensity parameters include grey scale in voxels, the continuity of the grey scale, and the direction of the grey gradient; The physical parameters include the shape, the size, the density and the textures of the foci; And the functional parameters include the local glucose metabolism rate, the local blood flow, the local blood volume, the pressure of oxygen in blood, the local consuming rate of the oxygen (CMRO2) et al. Since the analysis should be done at the voxel level in ROI by serials of the search processing, this process costs very much computing time. Therefore, the algorithm for fast calculation should be included in the pattern recognition process.

There are many theories or methods can be chosen for pattern recognition, such as the pattern matching, criterion function, objective function and determinant tree et al. [15, 16]. The automatic recognition of the medical images is an important technique to deal with the huge amount of imaging data. With the increase of the recognition ability, the more intelligent and the more automatic levels will be reached. However, the recognition process is an analytic optimizing and approximating process for the huge amount of imaging data, any improvement in the fast algorithm can reduce the computer time to make pattern recognition possible in the clinical application.

After the feature extraction and the suspicious foci in ROI were determined, the classification for these suspicious foci is the last step in MICAD. These parameters and features got from pattern recognition are also possible to be used as classification criteria, such as physical parameters of diseases: the needle degree of focus, the smoothness at focus edges, the shape of focus, the density, the symmetry and the temporal stability of foci et al. That means the classification process is used for focus identification, and the great differences of functional parameters are very useful for the classification process. The extracted features should be cataloged into different types, such as the features based on the gradient, the features based on the shapes, the features based on the intensity and the features based on the physiological parameters et al.

The commonly methods used in classification include methods based on regulations, methods based on discriminating thresholds, methods based on the Bayes statistical criteria, and fuzzy logistics, artificial neural network, genetic algorithm et al. [17-24]. The dynamic automatic pattern recognition and classification are the most interested technologies in our group, which is useful not only for MICAD, but also for treatment of disease, such as the treatment of the brain tumor by the image guided surgery or radiotherapy.

3. MICAD in China

In China, MICAD has been considered as a new technology to be developed in hospitals, but most of hospitals have not equipped formal products of MICAD. Most of laboratories in China are still on the way to develop these technologies.

As to the research and development, there are many laboratories involved in the field. Among them, the Medical Physics laboratory of Peking University (MPLPKU) is a leading laboratory in China. This team has integrated the knowledge of computer science, anatomy, physiology and psychology as well as the experience on pathology together. With the rapid progress of medical imaging technologies, the high quality 3D imaging facilities have been populated in China. Moreover, with the abundance of patient sources, development of MICAD is predominance in China. MPLPKU group pays much attention to the functional imaging facilities, such as MRI and PET, because MRI possesses high spatial and temporal resolution with dynamic display and multiple imaging parameters. PET image is the only information source at molecular level. MPLPKU group involves all these modern imaging
technologies including the X-ray imaging of planner (CR, DR) and CT. Therefore, MICAD will be accelerated for the further development.

The research progress in MPLPKU is focused on the brain tumor and prostate tumor simultaneously. The main brain tumor is glioma, which is the most important tumor in head, because in the most cases the groups of cancer cells in glioma not only exist in the solid part, but also widely spread into normal tissues (see Fig. 5), which forms sub-foci (the foci that their sizes are smaller than image spatial resolution). Therefore, the functional information from fMRI or PET needs to be integrated into MICAD. Our purpose is not only to determine the benign or malignant, but also to determine the type and grade, and to establish the therapy plan for surgery and radiotherapy.

4. Conclusion

This paper is a review and an introduction of the research progress on MICAD in MPLPKU. From view of future development, the expected technologies should be the information integration to completely understand the human from both directions of microscopic level at molecular and the macroscopic level with mini-second dynamic capability. Therefore, for the recent requirement of MICAD, the images should be acquired and integrated in ms level of temporal resolution and sub-millimeter level in spatial resolution. Then, the two directions on the microscopic and the macroscopic levels will meet each other in 21 century.

Fig. 5  Types of glioma. I : only solid part, II : solid part and sub-foci, and III : only sub-foci.

References

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