Elektrotehniški vestnik 77(2-3): 161-168, 2010
Electrotechnical Review: Ljubljana, Slovenija

Overview of the popular image techniques and services in biomedicine

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Abstract. Imaging is one of the most important information sources in medicine and biology, as it opens up new ways to see the inner workings of the body, measure biological functions, evaluate cellular and molecular events using less-invasive procedures and makes the diagnostic processes more effective. At the same time, there are now possibilities to share huge quantities of medical information between different medical specialists and technical researchers. In this paper we present an overview of the popular techniques and services for capturing and analyzing medical and biological image.

Key words: medical imaging, biological imaging, medical services, DICOM, PACS, matlab

Pregled sodobnih slikovnih tehnik in storitev v biomedicini

Povzetek. Razvoj sodobnih medicinskih tehnik in biomedicinskih raziskav je tesno povezan z razvojem zmoglivih slikovnih tehnik in računalniško obdelavo pridobljenih podatkov. Slike so eden najpomembniših virov informacij v medicini in biologiji in omogočajo v pogled v notranjost telesa, spemljanje različnih bioloških funkcij in preiskave na celični in molekularni ravni. Neznansko količino pridobljenih slikovnih informacij je treba hitro in ustezno računalniško obdelati in pridobiti kakovostne diagnostične rezultate. Poleg tega je treba omogočiti učinkovito izmenjavo diagnostičnih in rasiskovalnih podatkov med specialisti različnih področij, pri čemer je treba uporabiti sodobne formate shranjevanja in prenosa v biomedicinskem okolju. Zaradi potreb po učinkoviti diagnostiki pa moramo omenjene sodobne sisteme nadgraditi z metodami za obdelavo slikovnih podatkov in diagnostiko. Predstavitev sodobnih metod prenosa in metod nadgradnje z novimi funkcijami je v pregledni obliki podana v članku.

Ključne besede: slikovne tehnike v medicini, slikovne tehnike v biologiji, DICOM, PACS, matlab

1. Introduction

Digital image processing is now being widely used in many spheres of human activity. As technical capabilities develop, people are becoming increasingly more demanding when it comes to the quality of the services that they receive, particularly in the area of medicine. However, in many cases the time and money that are spent do not yield the desired results, which are why many experts are involved in the development of image processing, as one of the most rapidly expanding fields of research.

When a researcher is developing a new image processing technique or manipulating an image, he or she is confronted with the question of how this technique will improve a clinical diagnosis. It is very important to know from where and how to acquire the original image in order to avoid unnecessary calculations and to make the whole process – from image capture to identification – as quick as possible.

It has long been known that the noise characteristics, contrast and resolution of an image need to be taken into consideration at the beginning in order to appropriately evaluate the quality of an image. In many cases, rapid diagnostics are necessary; therefore, speeding up of the process is an important issue as well. Medical experts frequently face problems regarding medical image datasets, for example, feature extraction, segmentation, texture, shape and motion measurements, spectral analysis, representations of pictorial data, visualization, simulation using virtual organs and telemedicine. All those problems can, however, be overcome by applying mathematical techniques. Medical image processing has become a key technology for high-tech applications in medicine.

Another important point that needs to be kept in mind is that biomedical imaging methods can open up new ways to see the inner workings of the body, measure biological functions, and evaluate cellular and molecular events using less-invasive procedures.

However, further developments are needed to improve the planning and performance of computer-aided diagnoses. For this reason, a summary of new technologies and some ideas for medical and biological imaging are presented in this paper.

Received 29 April 2010
Accepted 21 May 2010

2. Popular Imaging Techniques

Since the discovery of X-Rays, imaging technologies have been part of medicine and biology.

2.1. Actual Imaging Techniques in Medicine

Medical imaging [1], [2] includes a variety of techniques [3], like X-ray imaging, computer tomography (CT), ultrasound imaging or sonography, magnetic resonance imaging (MRI), magnetic resonance spectroscopy (MRS), single photon emission computed tomography (SPECT), positron emission tomography (PET), electrical impedance tomography (EIT), magnetic source imaging (MSI), fluorescence imaging and medical optical imaging. Digital X-ray images are continue to be the most widely used method in hospitals, but fMRI (functional MRI) [4] is becoming the method of choice for the diagnosis of brain functions, as well as for an assessment of the potential risks of surgery and other invasive treatments. For more detailed observation of solid tumours or problems in the abdomen, computer tomography can be used [4], but this technique involves larger radiation doses than the more common, conventional X-ray imaging procedures. Ultrasound is used for the visualization of muscles, tendons, and many internal organs. Their size, structure and any pathological lesions can be detected with this technique. A SPECT scan is primarily used to visualize blood flow through the arteries and veins, while PET [5] is a new scanning technique in medicine that is used to measure important body functions, such as blood flow, sugar metabolism, brain activity and can help doctors evaluate how well organs and tissues are functioning.

Today, there are a large number of interdisciplinary research groups which include specialists from medicine and other research fields. Their research activities are focused on both improving existing image techniques and developing new methods for image processing and analyses.

2.2. Actual Imaging Techniques in Biology

Imaging biological specimen is an area of great interest in research and medicine. Imaging techniques used to view and investigate samples or objects that cannot be resolved with the naked eye, i.e., objects that are too small to see, include various microscopy and spectroscopy techniques. Here, advances in digital imaging and analysis have enabled microscopists to make quantitative measurements, quickly and efficiently.

The most popular microscopy image techniques in biology are optical microscopy, electron microscopy, scanning probe microscopy, fluorescence microscopy and techniques involving more advanced microscope designs, such as the confocal fluorescence spectroscopy, multi-photon spectroscopy etc.

Optical microscopy can only image dark or strongly refracting objects, with the resolution limited by the wavelength of visible light (which is around 0.2 μm). Electron microscopy, in contrast, uses a particle beam of electrons to “illuminate” the specimen and create a magnified image of it. The resolution limit of electron microscopy is around 0.05 nm, but this technique does not allow the imaging of live samples. In contrast, scanning probe microscopy forms images of surfaces using a physical probe that scans the specimen. This probe impinges on the sample surface to acquire measurements and so can mechanically damage cells and tissue. Atomic force microscopy (AFM) or scanning force microscopy (SFM) have resolution of fractions of nm, than 1000 times better than the optical diffraction limit. Fluorescence microscopy [6] is probably the most widely used microscopy technique at the moment. Instead of light reflection and absorption it makes use of the phenomena of fluorescence. The advent of fluorescence microscopy has been a major step forward in the study of living cells. In fact, a protein or other component of interest in the specimen can be "labelled" with a fluorescent molecule called a fluorophore. This technique is generally used as a non-destructive way of tracking or analyzing biological molecules by means of fluorescent emission [7]. With the development of new molecular probes [8], like probes for organelles, lipids, membranes and endocytosis, imaging can be used not only to visualize gross anatomical structures, but also to visualize the substructures of cells and monitor the dynamics of molecules.

Labeling multiple proteins with different fluorophores makes it possible to visualize multiple targets within a single image. Fig. 1 illustrates a pair of cells that have been labelled with different fluorophores for nuclei, Golgi apparatus and a microfilament network, and photographed in the microscope to reveal the internal structure. Three separate pictures are captured, one for each fluorophor, and then they are superimposed into a new picture.

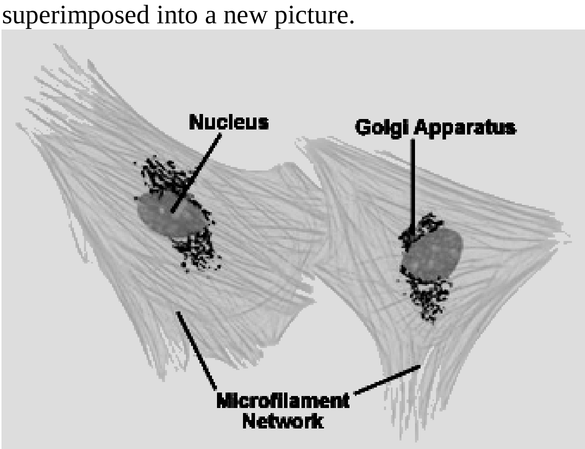

Fig.1 Pair of skin cells that are labelled with fluorescent probes and photographed in a microscope to reveal the internal structure [9]

Molecular imaging techniques make it possible to determine the temporal and spatial distributions of biological processes throughout an intact living specimen. Properly tagged molecules can be visualized, leading to insights into cell function, membrane binding sites, etc.

Other standard image techniques, like microCT, microMRI, fMRI, MRS, microPET, are also frequently used in biological image processing [10]. In molecular imaging, PET and SPECT use radio-labelled molecules to image the molecular interactions of biological processes in vivo. PET provides a novel way for molecular diagnostics to come together in the discovery of molecules that can be used in low-mass amounts to image the function of a target.

To allow a visualization of the internal, three-dimensional structure of living tissue, new imaging techniques with optical sectioning have been developed, the most important of these being confocal microscopy and multi photon microscopy.

Upgrades of popular microscopes techniques include wavelength-dependent measurement or spectro-microscopy [11], which includes the acquisition of wavelength-dependent images from biological specimen. Imaging is, therefore, a valuable tool to obtain information about the in-vivo molecular interactions important in biology that cannot be obtained through any other method. As a result, it can help to improve the efficiency of both pre-clinical and clinical research. However, besides development of new image-capturing techniques, fast and efficient algorithms for recognition and tracking the observed molecular structures inside the tissue need to be improved [12], [13].

3. Popular standards in medical imaging

When computer tomography was introduced, as the first digital modality, the importance of digital medical image processing increased dramatically. Today, not only has digital medical imaging grown very rapidly, but so has the ability to share this information - in seconds - across the globe. This has, as a result, maximized the usefulness of each image. DICOM and PACS specify a standard method for transmitting medical images and all the information related to them. Of course, new tools have also been created for viewing and analyzing these formats.

3.1. DICOM Basics

DICOM (Digital Imaging and Communication in Medicine) is widely accepted as a standard in medical imaging techniques; it is now an indispensable component in the integration of digital medical imaging systems.

The captured images can be written to files for offline storage on a picture archiving system, CD, or any other type of storage device. Each DICOM file may (or may not) include a header consisting of a preamble and a prefix that represents a separate class of information. For example, a DICOM file may represent the computed tomography image class, and another DICOM file may represent the radiotherapy structure set class. The header can include information such as personal patient data, the type of study, the equipment used, image dimensions, diagnostics, graphics and waveforms. The images and data are both stored in the same file. The purpose of this is to allow healthcare personnel to share images from different modalities and from different vendors on the same network.

The DICOM network services are based on the client/server concept. The most basic DICOM service is "image transmission" or in DICOM terminology, "Storage Service Class". In the case when two DICOM applications want to exchange information, they can establish a connection and agree on the communication and imaging format parameters. DICOM is available for any image technique and it works with MPEG-4.

The DICOM system provides:

- Network-oriented services: image transmission, archiving and integration techniques.
- Data structuring for medical images and related data.
- Formating for storage-media exchange.
- Information Object Definitions.
- Service Specifications.
- Data Structures and Encoding.
- Message Exchanging.
- Network Communication for Message Exchange.
- Media Storage and File Format for Media Interchange.
- Greyscale Standard Display Functions.
- Security and System Management Profiles.
- Content Mapping Resources.
- Explanatory Information.

DICOM has become an indispensable component for the integration of digital imaging systems in medicine. It offers solutions for many communication related applications.

The official DICOM homepage is available at NEMA's Official DICOM Web Page [14]

3.2. PACS Basics

PACS (picture archiving and communication systems) was developed by the American Institute of Physics (AIP) and has been used in Physical Review since 1975 to identify the fields and subfields of physics. It also enables images such as X-rays and scans to be stored electronically and viewed on screens, creating a near filmless process.

In medical imaging, PACS is a combination of hardware and software dedicated to the short- and long-term storage, retrieval, management, distribution, and presentation of images. Combined with the available and emerging web technology, PACS has the ability to deliver a timely and efficient access to images, interpretations, and related data.

The PACS system provides:

- Method and Process of Data Organization.
- Service Flow of Processing Medical Information.
- Service Category for Medical Visualization.
- Integration image techniques like cropping, zooming, brightness and contrast adjustment.
- Data storage, retrieval, distribution and presentation.

The design and development of a telemedicine imaging application, including a novel user interface and patient record-keeping require development and integration of DICOM and PACS. Today, the PACS system should work on DICOMization [15] so as to make images more accessible and avoid proprietary data formats. There is no automatic recognition, feature extraction and image analysis techniques included, which is why research activities are aimed at the inclusion of these processes to provide automated data analysis and offer good support to doctors.

4. Popular research tools in biomedical image processing

Modern image manipulation software packages usually support almost all major data formats. Some of them include simple tools, like greyscale thresholding, affine transformation, invariant converting, cutting, point detection, etc. Others use mathematical programs like Matlab and Mathematic for analysing data.

4.1. Matlab as research instruments in image processing

Many of the imaging projects that involve new algorithms and advanced computing methods were carried out in the Matlab environment. Matlab includes more than 35 toolboxes that realize many of the mathematical methods applicable in image processing and visualization.

Some of the most useful for biomedical imaging are the:

- Database Toolbox
- Image Acquisition Toolbox
- Image Processing Toolbox
- Spline Toolbox
- Statistics Toolbox
- Wavelet Toolbox
- Bioinformatics Toolbox

Matlab recently added support for the DICOM file format, but it does not have the ability to access PACS files. The basic program and its Image Processing Toolbox now provide both the read and write functionalities for DICOM-formatted files, enabling users to exchange medical image data and access metadata. With this expanded functionality, medical professionals can now easily write formatted files from the Matlab environment, greatly simplifying communication between their image devices. Reading DICOM files in the Matlab environment is relatively easy when using the *dicominfo* and *dicomread* functions.

Fig. 2 shows a presentation of a simple DICOM Viewer created by Konstantinos N. Plataniotis, Anastasios N. Venetsanopoulos [16].

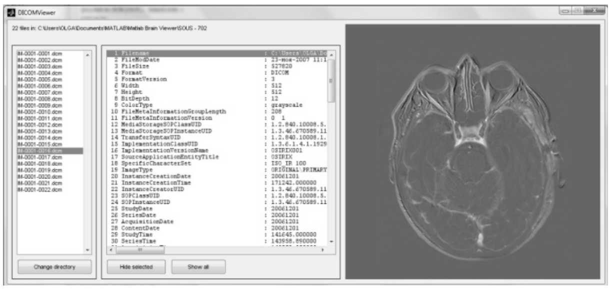

Fig. 2 Matlab visualization of DICOM files inside a program

The toolboxes implement only basic methods for image analysis and data mining, which can be included by the researches into their own methods by programming [17].

Matlab offers high-level facilities for dealing directly with mathematical constructs. The benefits of such an approach are:

- Excellent support for linear algebra and matrix operations. The software was originally developed as a linear algebra package and has efficient and numerically reliable algorithms for matrix inversion, eigenvalues, etc.
- Excellent toolboxes for image processing.
- Visualization of processing results. The built-in graphics and plotting functions are easy to use for both 2D and 3D plots.
- Convenient for real-time processing applications.
- Portability, as the software written in the Matlab language is portable to any platform that runs Matlab.
- Suitable structure for integration and connectively with most programs or operating systems.
- Personalization.

The Official Homepage [18], including a list of functions and toolboxes, is available on a web page.

4.2. Overview of popular programs for medical image reviewing and analysing

In most medical applications the presentation of images is based on DICOM or PACS files. Some of these presentation programs for monitoring of medical images are briefly presented below.

AFNI

AFNI [19] (Fig.3) is a set of C programs for processing, analyzing, and displaying functional MRI (fMRI) data - a technique for mapping human brain activity. It runs on Unix+X11+Motif systems, including SGI, Solaris, Linux, and Mac OS X. It is available free of charge (in C source code format, and some precompiled binaries) for research purposes. This program is oriented towards medical image processing supported by image-processing Matlab Toolbox.

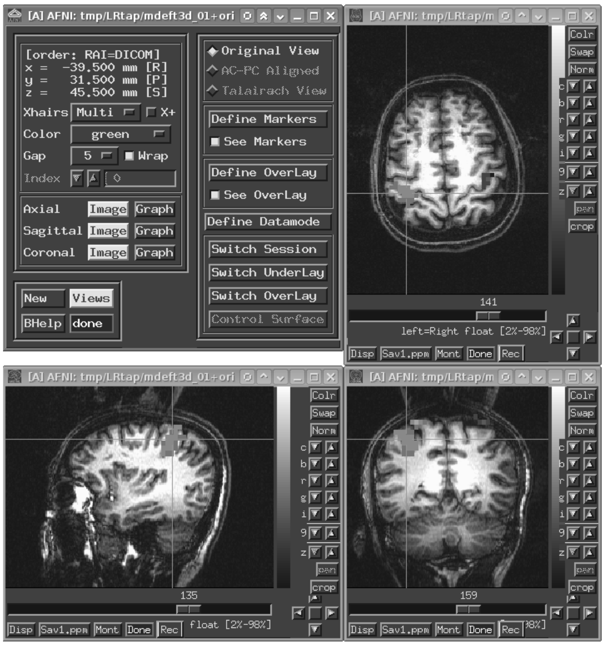

Fig. 3 Afni environment with an example for medical image analyzing [19]

The AFNI package provides:

- Switch viewing/analysis between many different datasets.
- Image display in axial, sagittal, and/or coronal views (including multi-image montages).
- Display of graphs (line and surface) based on data extracted from image viewers.
- Time-series graphing of square regions from image viewers.
- Linked image/graph viewing of multiple 3D datasets (e.g., linked scrolling through multiple brains).
- Transformation to Talairach coordinates (12 sub-volume piecewise linear method).
- Computation of activation maps using the "correlation method".
- Colour overlay of activation maps onto higher-resolution anatomical images (re-sampling of lower-resolution functionals is handled on the fly).

A disadvantage of AFNI is that it is not a real-time software package, which to some extent influences its range of applications [20].

3D-DOCTOR

3D-DOCTOR [21] (Fig. 4) works with CT, MRI, PET and other images in DICOM, TIFF, BMP, JPEG, Interfile, PNG, PGM, GIF, Raw Image Data, and other uncompressed image formats. Both greyscale (8-bit and 16-bit) and colour images are supported.

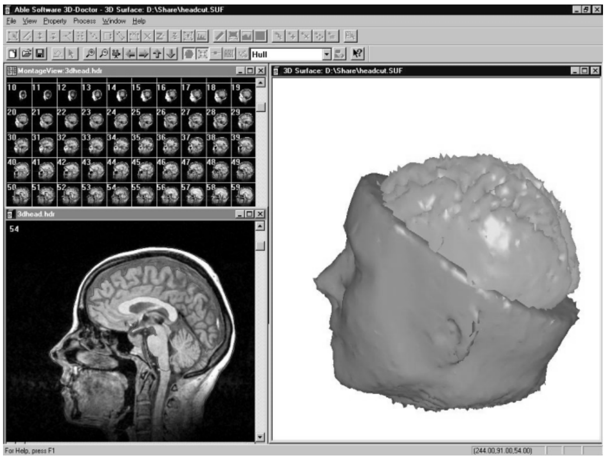

Fig. 4 3D-DOCTOR environment with an example of medical image analyzing [21]

The 3D Doctor package provides:

- Vector-based technologies for better 3D-mesh-model creation and editing.
- Surface model for high quality rapid prototyping.
- Smart memory management, with no limit to the number of slices that can be used.
- Handles DICOM and other image formats, such as TIFF, JPEG, PNG, GIF, BMP, Interfile and RAW.
- Works with greyscale and colour images
- Colour classification and separation.
- 3D image processing: image registration for multi-modality application, image fusion, image resizing, etc.

All the functions are tightly integrated into a single, easy-to-use package.

Image Processing includes the following possibilities:

- Automatic Texture-based Segmentation for greyscale and colour images.
- The Thresholding-based Interactive Segmentation for CT images.

- Region-based Object Segmentation and the easy-to-use polygon-based manual tracing.

Other 3D-DOCTOR image processing functions that can all be performed on 3D images include: template-based, scanned-film cropping; volume resizing; 3D image filtering; image rotation; orientation adjustment; contrast adjustment; background removal; image combination; linear feature extraction; pattern recognition; segmentation; image mosaic; and colour classification. 3D-DOCTOR provides two highly efficient disconsolation methods for 3D-image restoration and reconstruction, a fast, nearest-neighbour algorithm and an iterative maximum-entropy algorithm.

Evorad Research PACS

The "Evorad"[22] (Fig. 5) name stems from the phrase "evolution in radiology" and summarizes the introduction of a new approach to the development of medical information systems and, in particular, software for radiology laboratories. This approach is based on technologies, a commitment to user productivity, adaptability to user needs and total product-and-services quality.

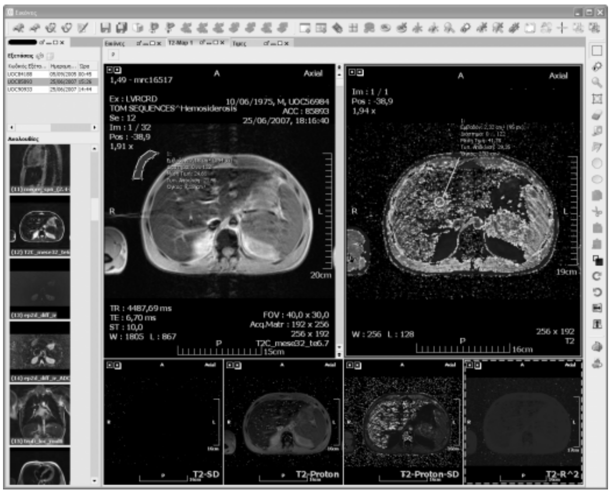

Fig. 5 Evorad Research PACS environment with example for medical image analyzing [22]

Software options for workstations and servers that add to the core functionality of the clinical Evorad RIS-PACS system are: a development environment for new image processing techniques, and tools for exporting measurements to worksheets for statistical processing and patient/examination grouping. The program has support for most operating systems, like Windows, Linux, Mac OSX, and Solaris.
The Evorad Research PACS package provides:

- Tabbed views allow arbitrary layouts of the image series.
- Transferring medical images to Matlab in the form of 3D or 2D matrices and back.
- Technical support to image processing.
- Batch data processing and image series synchronization.
- Instant access to patient and exam information, including a diagnosis text without leaving the image-reading window.
- Multiple exam/ROI export to Excel for statistical processing.
- Hanging protocols.
- Measurement and annotation tools (for example, ROIs, distance, angle, and arrow note).
- Export and import to DICOM or image formats.
- Export region-of-interest measurements to Excel

New image processing algorithms can be developed, tested and updated from within the PACS workstation. Since the workstation is connected to the central server, examinations. As soon as they are verified, new image processing techniques can be "published" for use by all the system users.

DICOMan

DICOMan [23] is a software system that aims to help tackle DICOM incompatibility problems in a do-it-yourself manner, which is much faster than waiting for the manufacturer's new release or patches. It helps you to address DICOM issues in order to meet immediate clinical needs. Non-DICOM images in common formats (BMP, GIF, J2K, JBG, JPEG, PCX, PNG, TGA and TIFF) can also be viewed, together with DICOM objects. It also equipped with a network analyzing tool.

The DICOMan package provides:

- Retrieve DICOM Objects
- Transferring via DICOM connection
- Edit DICOM Objects
- Anonymize DICOM Objects
- Convert Image Formats
- Create Virtual DICOM Phantom
- Generate AVI Movie

Medical imaging device companies, especially those with real-time embedded-system products, are often burdened with lengthy verification cycles. However, an integrated wireless technology could communicate with a gateway that connects to the medical centre's network and transmits data to health data stores for monitoring, control, or evaluating in real time or offline after storage.

These programs have simplification possibilities for extraction features from the biomedical images. The use of mathematical techniques can broaden the possibility of diagnostic image processes and help doctors to see information which cannot be detected with the eye.

5. Research Tendencies in Digital Biomedical Image Processing

When applying image processing to the fields of medicine and biology, the fundamental aspects - like image registration [24], segmentation and visualization, pattern recognition and classification - are very important for the doctor at work. When we talk about “patterns”, we refer to those objects or forms that we can perceive with whole image workflow. Pattern recognition is generally about how to classify and analyse data based on a priori knowledge or statistical information about the data. Pattern recognition is both increasingly popular and required, since more and more data is generated and this needs to be processed.

In fields like medical and biological imaging, there is a great demand for efficient and accurate image-content analysis. Here, the plausibility is very important. Therefore, with mathematically supported approaches we can overcome the problems dictated by image capturing technologies. The typical problems to be overcome after image registration are:

- Low resolution.
- High level of noise.
- Low contrast.
- Geometric deformations.
- Presence of imaging artefacts.

This is why the image has to be pre-processed, and after this step the methods for object recognition and classification can be developed and integrated in of the most popular medical and biological imaging environment.

6. Influence of applied mathematics

Development and implementation schemes for image processing without performing mathematical methods [25] of analyses are impossible. The history of scientific computing shows that the breakthroughs that led to massive speed-up would have been impossible without a deep understanding of the numerical mathematic. However, it is necessary to turn this intellectual power into efficient and robust software. The methods currently being used in image processing come from almost all branches of scientific computing, including fast Fourier and wavelet transforms, multigrid methods, dynamic programming, combinatorial optimization, computational Probability Density Estimation (PDE), numerical linear algebra, Monte-Carlo simulations, intelligent systems, etc.

The main goal of researches is to extend the popular packages with automatic biomedical object recognition and classification. We can use the image segmentation problems to illustrate how mathematics has contributed to image processing in the following steps: reading, analysis and implementation. The goal of segmentation is to divide up the image domain into simple pieces, so that image features such as the greyscale intensity or the colour are approximately constant or slowly varying in each piece. It is a challenging problem that is closely connected with edge detection. The efficiency of the “push and pull” between image analysis and applied mathematic will remain a strong factor in the future.

7. Summary

Modern medicine has to try and take care of each and every patient. For this reason, DICOM and PACS were created as standards for the writing and saving of medical data. Huge archives of diagnostic images have an electronic format that opens new possibilities for research. The integration of intelligence and mathematic together with image processing methods into medicine and biology provides useful support for doctors in the diagnostic processes, and helps to see the information in images that cannot be seen with the naked eye. In this case, image techniques can be used to extract the required information mathematically.

As a result of this, many experts are deeply involved in the development of medical and biological image processing tools. The main goal of searching is to create intelligent support systems that can develop the broad range of possibilities offered by image analysis.

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