Medical Image Analysis. An overview

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***Resumo* – Este artigo identifica várias metodologias de análise de imagem usadas num ambiente médico. O artigo está focado num pequeno número de exemplos publicados recentemente, cobrindo diferentes metodologias de análise de imagem, usadas na análise de diferentes tipos de imagens médicas. O artigo ilustra também como são aplicadas as técnicas de análise numa variedade considerável de imagens de diferentes órgãos ou estruturas, desde o coração ao cérebro, ou desde a língua ao pé. O artigo pretende dar uma visão geral diversificada desta área, procurando ser a via de entrada aos cinco artigos apresentados nesta edição especial de Imagem Médica. Estes artigos são eles próprios um bom exemplo da diversidade e potencial da análise de imagem médica.**

***Abstract* – This paper identifies various image analysis methodologies used in a medical environment. The paper is focused in a short number of examples published recently and covering different image analysis methodologies, used for analysis of different medical image types. The paper also illustrates how image analysis techniques are applied to a considerable variety of images of different organs or structures, from the heart to the brain or from the tongue to the foot. The paper is intended to be a diversified overview of the field, and acts as an introduction to the five papers presented in this special issue on Medical Imaging. They themselves are a good example of the diversity and potential of medical image analysis.**

I. INTRODUCTION

Medical images give information of size, shape and function of organs of the human body, being one of the most important tools in medical practice and an invaluable mean for establishing a diagnosis.

The use of computers for medical image analysis offer a broad range of new capabilities. It is the mean for quantitative measurement of several image parameters, in both 2D and 3D. It allows a fast detection of changes among images acquired in different time instants. The time interval can be a few seconds as in an angiographic sequence or several months for follow-up purposes, using images of the same modality. Data fusion among different imaging modalities became possible, allowing the combination of complementary information of a same patient. Image comparison from images of a same modality but from different patient is now possible and useful for studying a particular pathology or for indexing an image database. Movement characterisation of human organs or articulations and data visualisation of volumes and dynamic scenes are other examples where image analysis techniques play an important role.

From the point of view of the methodological approaches in image analysis there are several image analysis topics often used in medical imaging systems, including:

- Image segmentation, for delineating regions of anatomical or physiological interest. Adaptive thresholding techniques, deformable models, texture analysis, multiresolution approaches, mathematical morphology are examples of methods useful for segmentation.
- Image registration, allowing the comparison of images or fusion of images from different imaging modalities.
- Image characterisation for quantitative measurement of shape geometry, for similarity evaluation or for characterisation of anatomical or physiological parameters.
- Motion tracking and change detection allowing the characterisation of movement of organs or the detection of changes observed among images.

These methodological approaches have been applied in various applications and used in several medical departments. In this overview we present several examples of techniques used for imaging several organs or functions of the human body.

Table 1 presents an overview of image analysis methodologies used in medical imaging. It gives us an idea of different image analysis operations, using several approaches applied to different image types, resulting from imaging different organs or functions.

Table 1. Image analysis methodologies, operations and modalities used in medical imaging.

Organ or function imaged	Image analysis operation	Imaging Modality	Image analysis methodology	References
Arteries	Registration	CT	Edge detection, optical flow	[16]
Arteries	Segmentation	x-ray	Mathematical morphology, graph matching	[31]
Arteries	Segmentation	ultrasound	Snakes	[36]
Arteries	Segmentation	ultrasound	Contour boundary detection	[23]
Arteries	Characterisation	MR	Deformable models	[48]
Bone	Segmentation	MR	Probabilistic relaxation	[29]
Brain	Registration	MR, CT	Multiresolution, voxel similarity	[11]
Brain	Registration	MR	Unsupervised classification, morphological operators	[18]
Brain	Registration	MR, CT	Ridgness measurement, multiresolution method	[10]
Brain	Characterisation	MR	Deformable models, principal component analysis	[44]
Brain	Segmentation	MR	Multiscale representation, scale space	[30]
Brain	Segmentation	MR	3D image segmentation, deformable models	[32]
Brain	Segmentation	MR	Multiscale analysis	[20]
Brain	Segmentation	MR	Scale space	[22]
Brain	Registration	CT, MR	Surface based volume based techniques	[19]
Breast	Registration	MR	Pharmacokinetic modelling	[12]
Breast	Characterisation	x-ray	Decision support	[46]
Breast	Registration	x-ray	Interpolation, matching features	[17]
Breast	Segmentation	x-ray	Linear discriminant analysis, texture classification, thresholding	[25]
Breast	Detection	x-ray	Principal component analysis	[28]
Colon	Characterisation	endoscopy	Magnetic imaging	[47]
Ear	Segmentation	MR	Deformable models, matching	[27]
Eye	Registration	optical	Hierarchical methods, Simulated annealing	[14]
Eye	Registration	optical	Extraction of anatomical and pathological features, Hough transform	[13]
Eye	Registration	optical	Hough transform, mathematical morphology	[15]
Eye	Registration	optical	Edge detection, exhaustive search	[9]
Eye	Segmentation	optical	Active contour	[34]
Eye	Segmentation	optical	Mathematical morphology	[33]
Femur	Segmentation	CT	Active contours	[41]
Foot	Characterisation	optical	Special imaging system	[43]
Foot	Motion	optical	Deformable models	[53]
Gastrointestinal	Segmentation	endoscopy	Pyramidal structure, boundary detection, progressive thresholding	[39]
Heart	Motion	MR	Finite element modelling	[49]
Heart	Segmentation	ultrasound, MR	Active shape models	[21]
Heart	Motion	MR	Non-rigid motion, biomechanical modelling	[51]
Heart	Motion	ultrasound	Active shape models, contour tracker, stochastic methods	[50]
Hip	Characterisation	x-ray	Quantitative image measurements	[42]
Lungs	Characterisation	CT	Curvature analysis, Linear discriminante analysis	[45]
Lungs	Segmentation	CT	Neural networks, multi-gray level thresholding	[24]
Lungs	Segmentation	CT	Facet models, progressive segmentation	[26]
Oesophagus	Segmentation	ultrasound	Fuzzy logic, information fusion, snake model	[35]
Prostate	Segmentation	ultrasound	Genetic algorithms	[38]
Skin	Segmentation	optical	Colour segmentation, clustering	[37]
Tongue	Motion	ultrasound	Deformable contours	[52]
Tooth	Segmentation	optical	Feature detection, contour detection	[40]

This paper tries to give a broad overview of image analysis operations and methodologies used for various types of medical imagery.

After this introduction, the next section identifies the different types of medical images. Section III presents the most common image analysis operations and give examples of some of the most frequent methodologies. Finally, the paper concludes by presenting in Section IV the challenges and the new capabilities offered by image analysis for diagnosis.

Following this paper, this special issue on Medical Imaging presents five papers, organised as follows: the first two papers are on visualisation methods [54, 55]. [56] and [57] are examples of image characterisation. Finally, the paper by L. Alexandre *et al* is an example of image classification [58].

For further reading a list of review and survey papers is presented from [1] to [8].

II. TYPE OF IMAGES

There are several imaging modalities used in medical applications, and identified in Table 1. Among all the techniques, x-ray images plays an important role, since the beginning of the 20th century. This radiographic image is formed by the interaction of x-ray photons with a detector. The image is a projection of the attenuating properties of all the tissues along the path of the x-rays. This technique is used for imaging several organs, namely the breast [25, 29], the lungs [58], and the skeleton [41].

With x-ray computed tomography (CT) a planar slice of the human body is obtained, showing the anatomy in the section. Computed tomography has been used for imaging several organs, as the brain [11], the lungs [24, 27] or the femur [41].

Ultrasound is a form of radiation that, like x-rays, penetrates and interacts with the body, giving information about body structures. Examples appear for artery characterisation [23, 36], for imaging the heart [21, 50], the oesophagus [35], the prostate [38] and the tongue [53].

Magnetic resonance (MR), as cross-sectional tomography, can provide three-dimensional anatomical information and functional information, as well. Table 1 gives several examples of applications using MR images, namely for imaging the brain [18, 44], the heart [49, 51] and the bone [29]. The advent of tagged magnetic resonance images [3], [5], can provide information of cardiac deformation in three dimensions over time. In this technique certain tissues are magnetised using a special pattern (typically a spatial grid). The grid is visible in the first image and its deformation can be followed along the image sequence.

Another new imaging data set is phase contrast MR imaging. In this type of images the uniform motion of the tissue in the presence of a magnetic field gradient produces a change in the MR signal phase, thus providing a local estimation of displacement velocity [51].

Conventional image acquisition techniques, by using a general or special purpose TV camera, are also used in medicine. We call it optical imaging. The technique is used, for example, for skin characterisation [37], for imaging the eye [13, 33], or for the foot [43, 53].

Endoscopy is a frequent technique in medical practice allowing an organ to be imaged in situations where surface imaging does not work, because regions are obscured (by gas or bone). Examples are the imaging of the colon [47] or gastrointestinal applications [39].

The papers in this special issue also present different types of images: MR images in [55], x-ray images in [58] and optical imaging in [56]. Images obtained with a scanning laser ophthalmoscope are used in [57].

III. METHODOLOGICAL APPROACHES

Medical image systems use various image analysis operations. For the purpose of this overview, we group them on the following four classes: image segmentation, image registration, image characterisation and motion. Image analysis techniques are also used in image restoration, visualisation, simulation and medical robotics. They are not considered in this overview, because the main goal of these tasks is not the analysis of images. The references in this paper are organised in the above referred image analysis topics, together with a set of useful review and survey papers.

A. Image segmentation

In the context of medical imaging, image segmentation is an image analysis operation used for automatic or interactive image labelling into a set of regions with anatomical or physiological meaning. The main purpose of image segmentation is to give the medical doctor a better understanding of the spatial relationships, to improve the delineation of the objects to be visualised for diagnosis, surgical planning and surgical navigation.

There is not a general solution for image segmentation. Several approaches have been used. Table 1 gives some examples of different methodologies. We are going to briefly present some of them.

- *Thresholding* is the very basic image analysis operation allowing image segmentation based on pixel intensities. Image thresholding can be applied directly to the image without any pre-processing stage or after a special purpose image enhancement stage. In [39] the authors use a progressive thresholding technique based in the well known Otsu's method. This operation is used to find the darker regions in the images, which include the lumen, the main region to be detected. In [26] thresholding is used for pre-detection of suspicious areas in lungs. To calculate the optimum threshold the authors propose an iterative algorithm, including in the loop a region growing technique. Progressive thresholding is proposed for detection of suspicious areas in mammograms [26]. Multiple gray-level thresholding is the basic operation applied to identify the initial lung nodule candidates [24]. A single thresholding operation allows the definition of the seed points used for identifying microaneurysms in retinal images [33]. A supervised thresholding approach for segmenting the total brain [32] is another example of image thresholding.
- *Multiscale analysis* defines a set of image processing methodologies applied at variable image resolutions. These methodologies are used both for image representation, *e.g.* the pyramids, or for hierarchical image processing. They are useful for object coarse-to-fine detection or for speeding-up image analysis operations. A multiscale method (the hyperstack) is proposed to segment multi-dimensional MR brain data [20]. Beil *et al* follows a scale-space detection approach for edge detection in tomograms [22]. Niessen *et al* [30] adopt a multiscale representation of MR brain images and a multiscale linking model (the hyperstack) to group voxels into a number of objects based on intensity. In this special issue, Loke *et al* propose a multiscale representation and processing scheme for spatial smoothing and surface construction of MR images [55].
- *Mathematical morphology* is a theory successfully applied in the field of image processing and analysis. It defines a set of operations, the morphological operations, useful for extraction or changing shapes. Image segmentation is one of the possible applications. For instance, in [31] Kostas *et al* uses mathematical morphology to accurately

determine the skeleton of the coronary arterial tree. A mathematical morphological operator is used in a pre-processing phase to ease the detection of microaneurysms [33].

- *Classification methods* produce a class or an image segment, based on a local feature or set of features. T. Antoniadis develop a probabilistic relaxation technique for separating bone pixels [29]. Xu *et al* propose rule-based methods and neural networks to improve the detection of lung nodules [24]. [25] and [26] use heuristic approaches for classification of malignant masses in mammograms and lung nodules, respectively. Image segmentation based on colour features is proposed by P. Schmid to locate skin lesions [37]. The author use a modified version of the fuzzy c-means technique. L. Alexandre *et al* propose in this special issue a neural network approach for the detection of the occupation of the costal diaphragmatic angle in lung images [58].
- *Deformable models* are curves or surfaces that adapt themselves to fit an anatomical structure or pathological region. The evolution of the model is guided by simultaneous optimisation of two criteria. One measures the smoothness of a geometric model. The other is based on properties measured on the image. The evolution of the deformable model can be controlled, starting at a given position, and ending when the specified criteria reach a defined error margin. [2] and [4] are good survey papers on this topic. In [21] the authors describe a technique for building compact models of the shape and appearance of flexible objects (such as organs) seen in 2D and 3D medical images. H. Rifai *et al* present an image segmentation approach based on a 3D deformable model of the inner ear, using MR images [27]. The segmentation approach followed in [32] makes use of object shape statistics by restricting possible elastic deformations into the range of the training shapes. B. Solaimon *et al* [35] uses a dynamical model to define the oesophagus inner wall in ultrasound images. Deformable models have been applied in other ultrasound images, as in [36] for detection of carotid artery wall or in [38] for locating the prostate.

B. Image registration

Image registration is an important image processing operation aiming at the rigid or flexible matching of two 2D or 3D data sets. There are three main approaches for image registration: feature-based, surface-based or volume-based. In the first one, we have to define a set of corresponding points in the two images, either by automatic methods or, simply, by interactively indicating their position. In the surface-based techniques the two corresponding surfaces are matched by minimising a distance measure between them. Volume-based techniques make use of the relationship between voxel intensities to perform the registration. There are examples of registration of images acquired using the same imaging modality. Intermodality registration techniques have more and more interest in medical applications. J. West *et al* compares intermodality registration techniques [19] using CT images, MR images and images obtained using positron emission tomography. The results indicate that all the techniques have the potential to produce satisfactory results, but volume-based tended to give substantially more accurate and reliable results.

Perhaps the most relevant example of image registration appeared in the early 1980s. It was the digital subtraction angiography. Here the blood circulation in the blood vessels is characterised by subtraction consecutive frames. The motion compensation was performed using gray-level-based correlation techniques, allowing high quality subtraction. The references [7] and [16] present an excellent review on this topic. Another survey of hierarchical methods for image registration is presented in [6].

In ophthalmology there are several applications of image registration. A. Mendonça *et al* use the co-ordinates of pre-detected edges for alignment of retinograms obtained in different angiographic phases [9]. A. Pinz *et al* propose a method for extraction and superposition of anatomical and pathological features in different images [14]. For this purpose the authors developed an algorithm called "affine matching of intermediate symbolic representation". N. Ritter *et al* propose a registration method that combines the use of mutual information as the similarity measure and simulated annealing as the search technique [14]. F. Zana *et al* present an algorithm for temporal and/or multimodal registration based on point correspondence [15].

In CT and MR there are a great amount of examples for image registration. For example, in [10], a rigid automatic transformation of CT and MR images was proposed. 3D CT and MR ridgness volumes were accurately matched using correlation of gray values. In [11] a voxel similarity measure and multi-resolution optimisation technique were proposed for automatic registration of CT and MR images. In [18] the authors propose a technique for alignment MR brain data sets with a co-ordinate system.

For registration of breast images, the authors in [12] use MR images and in [17] x-ray images. In the later the registration is used for identifying differences between corresponding mammogram images, aiming at providing useful information about abnormalities in the mammograms. In [12] the authors propose to compute the optical flow for motion compensation in pharmacokinetic images. The authors argued that the quality of segmentation results improved after registering the images.

C. Image characterisation

The ultimate goal of some image analysis tasks is to obtain objective descriptions or measures of region properties or shape geometry, for similarity evaluation or for characterisation of anatomical or physiological parameters.

In a medical image analysis context, image features are measured aiming at obtaining a geometrical figure of an organ or of a pathological state, *e.g.* the length of the colon [47] or stenosis of a blood vessel [48]. Features can be extracted as an intermediate stage for classification of image regions, as in [46] where features are used for distinguishing malignant from normal mammograms.

A. Toni *et al* developed a system for quantitative evaluation of radiographic images. The system was used as a support tool for monitoring bone density evolution [42]. L. Serra *et al* proposed a system for measuring plantar pressures distribution and plantar shape distribution [43].

J. Martin *et al* present a framework for analysing the shape deformation of structures within the human brain [44]. The shape description allows the separation of disease deformation from normal deformations. The proposed shape description was in terms of physical and statistical deformation modes.

Curvature-based features and 3D texture features were used for classification purposes of lung nodules [45].

P. Taylor *et al* proposed an approach for the design of systems to assist in the interpretation of medical images [46]. In this framework (called CADIUM) different measures for the classification of calcifications in mammography images were evaluated.

D. Motion

The introduction of a fourth dimension (the time plus three spatial dimensions) makes 4D image analysis a difficult task. In a medical image analysis context, the study of left ventricular motion and deformation has been under research since the early 1980s. In a recent paper, this problem is addressed by G. Jacob *et al*, by presenting a visual image tracker on echocardiographic image sequences [49]. The authors define a shape space that describes heart wall deformations.

The heart wall motion characterisation is revisited in [50], using tagged MR images. The author present a method for reconstruction of 3D heart wall motion directly from tagged MR images, without detecting the ventricular boundaries or computing tag stripe locations.

Shi *et al* propose an integrated framework for the analysis of 3D motion and deformation of the heart [51] using phase contrast MR images. The proposed approach is based upon the use of image analysis strategies and biomechanical modelling.

Other deformation analysis strategies are presented in [52] and [53]. In the first one, Akgul *et al* study the surface movement of the tongue, using ultrasound images and deformable models. In [53] Tavares *et al* present an approach for matching image objects in dynamic pedobarography. Pedobarography refers to the measurement and visualisation of pressure distribution under the foot sole.

IV. THE CHALLENGES AND THE NEW CAPABILITIES OFFERED BY IMAGE ANALYSIS

The impact of imaging technologies in medical practice is increasing everyday, due to the improvements observed on the technologies used for image acquisition, analysis and visualisation. The advances at the technological level allowed the implementation of some of the procedures previously developed, opening simultaneously new horizons for the medical image analysis community.

There are several areas that have now and will have in a near future a prominent impact of image analysis technologies. Among others we may cite the following:

- *Computer aided diagnosis*. This area will benefit from contributions coming from different image analysis activities, including: the possibility of objective and quantitative measurement of shape and texture, both at 2D and 3D dimensions; change detection among two images, offering the physician the possibility of early detection of suspicious regions and aiding on the evaluation of the effectiveness of therapeutic treatments; information fusion, combining images acquired in different imaging modalities; image comparison for follow-up purposes.
- *Image guided surgery/intervention*. Imaging and interpretation of information from images become important in many surgical interventions. Problems of identifying or segmenting image structures is possible in near real-time, allowing minimally invasive interventions.
- *Atlas-based description of entire anatomical or functional regions*. Image comparison of images of different patients will allow a statistical representation of shape and image intensities. The atlas can help on the interpretation of locations of structures in any medical image, easing the detection and quantitative measurement of any abnormal change.
- *Deformation analysis*. Measurement of the deformation of moving and flexible organs from a temporal sequence of 3D images, will allow the quantitative evaluation of movement.
- *Visualisation of anatomical and physiological processes*. The qualitative evaluation of 3D and 4D images by the medical doctor in real-time of realistic images, allowing a realist presentation of the relative positions of different structures.

The new imaging techniques and methodologies will certainly play a relevant role in other medical activities, namely for the control and validation of therapeutics, namely in radiotherapy, traditional surgery, video-surgery, among others.

V. CONCLUSION

This paper tried to identify various image analysis methodologies used in a medical environment. The paper also showed several modalities applied for imaging a great variety of organs. I had not the ambition to be exhaustive. I just focused in a short number of examples published recently and covering different image analysis methodologies, different image types and having as objects different organs. I hope this gives the reader a diversified overview of the field. A deeper description of specific techniques are described in the following papers presented in this special issue.

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