Biomedical Engineering Master

Analysis of structures in Medical Images – Application in Resonance Magnetic Images of Female Pelvic Cavity

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Analysis of structures in Medical Images - Application in Resonance Magnetic Images of Female Pelvic Cavity

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Finally, thank you to my aunt Maria José Barroso for all the helps and supports.

This would not have possible without them.
Abstract

The Computer Vision is one of the areas of science that has given prominence by the scientific community. This interest is due to its wide range of application areas including Medicine, where the automatic segmentation of anatomical structures in medical images, means a profitable of time and resources of health professionals involved. The image segmentation is the process of dividing an image into homogeneous sub-regions. By homogeneity, it is understood according to some characteristics: such as color or grayscale. The segmentation process can be done manually, semi-automatic or automatic.

These processes of segmentation can be performed on still images or even over image sequences and often constitute the first step of more complex Computer Vision methodologies. For example, in the area of medical imaging, is common to 3D reconstruction of structures represented in images, as usual the first step consists in the segmentation of the structure under study of each image that represents the medical examination in question.

With this monograph it was intended to study customary methods in the area of Computer Vision to target objects represented in medical imaging, semi-automatic or fully automatic, the chief aim of its application to target structures in images of the pelvic cavity of women.

As some of the structures of the pelvic cavity of women are of reduced thickness, special attention will be given to techniques for segmentation of objects of small thickness.

The reason why the pelvic cavity of women deserve major emphasis in this monograph, is due to the fact that we still are not common to computational techniques appropriate to target structures in the images of this anatomical area of the human body.
# Index

I – Introduction .............................................................................................................. 17
  1.1 – Motivation ........................................................................................................ 18
  1.2 – Objectives ......................................................................................................... 20
  1.3 – Structure ........................................................................................................... 21
II – Female Pelvic Cavity .......................................................................................... 22
  2.1 – Introduction ..................................................................................................... 23
  2.2 – Anatomy ........................................................................................................... 24
    2.2.1 - Posterior Compartment ......................................................................... 24
    2.2.2 - Anterior Compartment ......................................................................... 27
    2.2.3 - Middle Compartment ........................................................................... 28
    2.2.4 - Pelvic Girdle ......................................................................................... 33
  2.3 – Physiology and Histology ............................................................................... 34
    2.3.1 - Skeletal System ....................................................................................... 34
    2.3.2 - Muscular System ..................................................................................... 35
    2.3.3 - Blood Vessel Structures in the Pelvic region ......................................... 37
    2.3.4 - Digestive organs of the pelvic cavity ..................................................... 41
    2.3.5 - Urinary system ........................................................................................ 42
    2.3.6 - Reproductive System .............................................................................. 43
  2.4 – Pathology .......................................................................................................... 46
  2.5 – Summary .......................................................................................................... 50
III – Medical Imaging .................................................................................................. 52
  3.1 – Introduction ..................................................................................................... 53
  3.2 – History of Medical Imaging ............................................................................ 54
  3.3 – Imaging Systems ............................................................................................. 55
3.4 – Magnetic Resonance Imaging ........................................................... 58
  3.4.1 - Fundamentals of MRI ................................................................. 58
  3.4.2 - Fundamentals of MRI Instrumentation .......................................... 63
  3.5 – Summary ......................................................................................... 69

IV – Image Processing and Analysis .............................................................. 70
  4.1 – Introduction ..................................................................................... 71
  4.2 – Digital Image .................................................................................. 72
  4.3 – MATLAB and the Image Processing .................................................. 74
  4.4 - Image Processing and Analysis .......................................................... 76
    4.4.1 - Image Enhancement ..................................................................... 77
    4.4.2 – Image Segmentation .................................................................... 84
  4.5 – Summary ......................................................................................... 90

V – Final Considerations and Future Perspectives ......................................... 91
  5.1 – Final Considerations and Future Perspectives ...................................... 92

References .................................................................................................. 94
List of Figures

Figure 2.1: Female pelvic organs in a sagittal view a); Muscles of the pelvic floor b) (images from Hamm, 2007)……………………………………………………………………..25

Figure 2.2: In this figure is possible see the anococcygeal body (a), the levator ani muscle (b), the rectovaginal fascia (c), the anorectum (d), the hypogastric plexus (e), the uterosacral ligament (f), the tendinous arch (h), and the perineal membrane (g) (images from Hamm, 2007)……………………………………26

Figure 2.3: Mid-Sagittal MR image of an adult female: The perasacral space is indicated by the arrows and the rectum region by r (image from Hamm, 2007)……………………………………………………………………………………………………26

Figure 2.4: Anterior compartment. Axial section (400µm) of a 24-week-old female fetus with the semicircular urethral sheath (indicated by arrows) (x12) (a); Sagittal section (500µm) of a 13 to 14-week-old female fetus with pubovesical ligament (indicated by white spots); Pubic Bone, pbo; Urethra, u; Levator ani muscle, lam (images from Hamm, 2007)…………..27

Figure 2.5: Axial section (400µm) in a female newborn specimen (x4); Urethra - u; Vagina - v; Rectum – r; Puborectalis muscle (arrows) (image from Hamm, 2007)………………………………………………………………………………………………………28

Figure 2.6: In this figure is represented the mesosalpinx (a) and the mesometrium (b) (images from Hamm, 2007)………………………………………………………………………………………………………………….29

Figure 2.7: Anatomic draft of the uterine cervix (coronal view, image from Hamm, 2007)………………………………………………………………………………………………………………………………………..30

Figure 2.8: Anatomic draft, which presents the strong relation between uterine arteries and ureter (indicated by an arrow, image from Hamm, 2007)………………………………………………………………………………………………………………………………………..30

Figure 2.9: Magnetic resonance image (MRI) of a healthy woman during early proliferative phase (sagittal plane, image from Hamm, 2007)……………….31

Figure 2.10: Posterior view of the broad ligament and ovarian attachments with the fallopian tube separated from the ovary (image from Hamm, 2007)………………………………………………………………………………………………………………………………………..31

Figure 2.11: Ovarian Fossa (image from Hamm, 2007)…………………………32

Figure 2.12: Vagina - Images in sagittal (a) and axial (b) orientation (images from Hamm, 2007)………………………………………………………………………………………………………………………………………..33
Figure 2.13: Pelvic Girdle (image from White, 2005).................................33

Figure 2.14: Hyaline cartilage: photomicrograph of hyaline cartilage covered by perichondrium. Chondrocytes within lacunae are surrounded by cartilage matrix (image from Seeley, 2004).........................................................35

Figure 2.15: Ossification: osteoblasts on a preexisting surface, such as cartilage or bone. The cell processes of different osteoblasts joining (a). Osteoblasts have produced bone matrix. The osteoblasts are now osteocytes (b). Photomicrograph of an osteocyte in a lacuna with cell processes in the canaliculi (c) (image from Seeley, 2004).........................................................35

Figure 2.16: Muscles of the pelvic floor and perineum – inferior view: male (a) and female (b) (Image from Seeley, 2004)...............................................................37

Figure 2.17: Histology of a blood vessel – the layers, or tunics, of the blood vessel wall includes the intima, media, and adventitia. A vasa vasorum is a blood vessel that supplies blood to the wall of the blood vessel (image from Seeley, 2004)..........................................................................................38

Figure 2.18: Arteries of the pelvis (image from Seeley, 2004)....................39

Figure 2.19: Branches of the aorta (image from Seeley, 2004)..................39

Figure 2.20: Inferior vena cava and its tributaries (image from Seeley, 2004)........................................................................................................40

Figure 2.21: Histology of large Intestine (image from Seeley, 2004).........41

Figure 2.22: Ureters and urinary bladder (image from Seeley, 2004). ......42

Figure 2.23: Histology of ovary (image from Seeley, 2004).....................43

Figure 2.24: Leiomyomas of the uterus (image from [Rubin, 2008]). ......48

Figure 3.1: The two primary MRI contrast mechanisms, T1 and T2. T1, illustrated on the left, describes the rate at which the equilibrium magnetization is restored after it has been disturbed. T1 contrast is produced by imaging before full recovery has been obtained. T2, illustrated on the right, describes the rate at which the MRI signal decays after it has been created. T2 contrast is produced by delaying data acquisition, so shorter T2 components produce an inferior signal (from Bronzino, 2000)........................................................................................................62

Figure 3.2: Digital and analog domains for MRI imaging. MRI involves the flow of data and system commands between these two domains (from Schenck and Leue, 1991)..................................................................................64
Figure 3.3: Block diagram for an MRI scanner. A general-purpose computer is used to generate the commands that control the pulse sequence and to process data during MR scanning (from Schenck and Leue, 1991).............64

Figure 3.4: Permanent magnet. The figure shows a schematic cross-section of a typical permanent magnet configuration. Electromagnets have a similar construction but are energized by current-carrying coils wound around the iron yoke. Soft magnetic shims are used to enhance the homogeneity of the field. (from Schenck and Leue, 1991)............................................65

Figure 3.5: Schematic drawing of a superconducting magnet. The main magnet coils and the superconducting shim coils are maintained at a liquid helium temperature. (image from Schenck and Leue, 1991)...............67

Figure 4.1 – Polychromatic Image (Image from Mendonça, 2010).........73

Figure 4.2: Representation of Image processing Toolbox and its functions.................................................................74

Figure 4.3: Kernels, which represent arithmetic mean filters (Image from Mendonça, 2010)........................................78

Figure 4.4: 3x3 Discrete Gaussian smoothing Kernel (Image from Mendonça, 2010).................................................................78

Figure 4.5: The result of a median filter in an image with salt and pepper noise (Image from Mendonça, 2010). ........................................80

Figure 4.6: Image shows a representation of the histogram stretch process (Image from Mendonça, 2010)................................................82

Figure 4.7: Binary Thresholding Function (Image from Hannah Patel, 1995)...................................................................85
List of Tables

Table 1: Properties of the skeletal system (from Seeley, 2004 and White, 2005) .................................................................................................................. 34

Table 2: Histology and Physiology of the muscular system (from Seeley, 2004). ............................................................................................................. 36

Table 3: Muscles of pelvic floor and perineum (from Seeley, 2004). .......... 37

Table 4: Arteries of the pelvis (from Seeley, 2004). ................................... 39

Table 5: Veins Draining the Pelvis (from Seeley, 2004) .............................. 40
I – Introduction
1.1 – Motivation

The pelvic cavity is one of the body’s most interesting organs, but unfortunately, also one of the least understood and most neglected. Outside of health-care circles, the pelvic floor is virtually unknown. In contrast, the pelvic floor is vital for the reproductive functions. In women, it becomes even more crucial to the health and happiness of the individual, and is intimately involved in labor and delivery. With its central role in sexuality and childbirth, the female pelvic floor is most intimately concerned with femininity. The female pelvic cavity is essential in several medical disciplines such as gynecology, obstetrics, urology and gastroenterology. This cavity can be affected by many different diseases and by many drugs in many different ways. Damage to the pelvic cavity not only contributes to urinary incontinence but can lead to pelvic organ prolapsed.

For analyze this body region is necessary use imaging techniques. Diagnostic imaging technology has transformed the practice of medicine. As a result of technological changes, medical experts are now able to provide more precise and less invasive care, leading to better prevention of illness and better clinical outcomes. In fact, diagnostic imaging has become the standard of medical care for virtually all major medical conditions and diseases, including cancer, stroke, heart disease, trauma, and abdominal and neurological conditions. Pursuant to this higher standard of care, diagnostic imaging has grown across the world.

A wide variety of imaging methods are nowadays used to visualize the pelvic floor. However, one of the most widely used method for observation of this area of the body is magnetic resonance. Through this technique it is observed that the medical images contain anatomic and functional important information, which reflects the organ’s shape and the patient condition. For the proper analysis and validation by a technical and also can obtain the potential maximum of the recorded data, the images have to be processed.

The observations of medical images for medical are, in most cases, qualitative and are only based on the expert’s visual sense. To improve the observation and make it more quantitative can be accomplished with an automated processing and a computational vision processing.

In order to make the automatic analysis of the pelvic cavity recourse to the computational vision, which is the capacity to describe or analyze images by using computational resources. For human, this process is relatively simple,
due to power of their vision system. The importance of this system has led a large number of investigators trying to play it computationally, through the development of automatic systems capable of performing some of their functions.

The enhancement of the structures, which are present in medical images, is an important step that can make possible a good segmentation and analyzing. The segmentation and analyzing of the structures, which are represented in medical images, are one of the areas of Computational Vision that demonstrated a greater development in the last years.

There are a great variety of approaches to develop models that can make be possible the characterization, recognition and simulation of medical images.

This chapter aims to expose the main objectives of this work, and describe the organization adopted for this report.
1.2 – Objectives

The principal aims of this work are:

- Study about the anatomy, physiology, histology and pathology of the female pelvic cavity to know the forms, structures and principal diseases of this region;

- Understand imaging techniques, specifically the techniques of magnetic resonances;

- Describe concepts related to image processing and computer vision.

The work presented in this report, had as main objectives the creation of a survey, the study, description and analysis of existing techniques for the medical images processing and analysis.
1.3 – Structure

The report is divided in the remaining chapters:

- **Chapter I – Introduction**

  In the present chapter can be observed the monograph theme and his importance, the motivation that led to do this work and the fulfilled objectives.

- **Chapter II – Female pelvic cavity**

  In this chapter is made a briefly description on the Anatomy of the female pelvic cavity, is performed the characterization of the physiology and histology of the various physiological systems in order to understand the biological processes that involve this region. Finally, the chapter presents the major diseases that affect this human body region.

- **Chapter III – Medical Imaging**

  In this chapter is described the historical evolution of the medical imaging, and presented the features of a large variety of imaging systems, as well as the detail description of the Magnetic Resonance Imaging technique.

- **Chapter IV – Image Analysis**

  Afterwards, in chapter IV is considered the principal theme of this work. Hence, the chapter contains the description of digital image, refers the processes that are involved in creating a digital image, and enumerates its characteristics. Then, is presented the fundamentals of the computational vision or image analysis. Further, is study the image enhancement and segmentation methods.

- **Chapter V – Final Considerations**

  Finally, this chapter presents the final conclusions and perspectives of future work.
II – Female Pelvic Cavity
2.1 – Introduction

In this chapter it will be presented the anatomy, physiology, histology and more frequent pathologies of pelvic cavity.

All subchapters have a particular interest to be analyzed and studied because they represent a group of organs or elements that will be digitally analyzed from medical images. Therefore, it is important to know their macroscopic form in order to facilitate its recognition and know which characteristics we can use to do the digital processing later.

Histological and Physiological analysis is realized to know the elements on a functional level and to foreshadow the possible textures that these elements can indicate. Once knowing the more frequent pathologies, the analysis will be possible if an element doesn’t match the standard ones.

The knowledge of pathologies provides new sights for an imaging analysis more focused on the classification and digital diagnosis.
2.2 – Anatomy

The pelvic floor is characterized by a complex morphology because different functional systems join here. These regions are subdivided according to functional and clinical requirements. The actual clinical subdivisions discern an anterior, middle and a posterior compartment [Crocco, 1988; Hamm, 2007].

A clear understanding of the pelvic anatomy, Figure 2.1.a, is crucial for the diagnosis of female pelvic diseases.

The anterior and posterior compartment may also be found in male.

2.2.1 - Posterior Compartment

The skeletal elements of the sacrum and the coccyx dorsally are the borders of the posterior compartment. These are completed by the anococcygeal body, a stratified non-ligamentous structure in which fleshy muscle attachments underlie a tendon, Figure 2.a, dorsocaudally and by the components of the levator ani muscle, Figure 2.b, laterally and caudally. All components of the levator ani muscle are found in the posterior pelvic compartment, the pubococcygeus muscles and the
iliococcygeus muscles constitute an irregular plate and insert into the coccyx, Figure 2.1.b. The inferior compartment, the puborectalis muscles, does not insert into any skeletal structure, but is continuous with the external anal sphincter caudally, although it is not a totally circular muscle.

The rectovaginal fascia, plate of dense connective tissue, smooth muscle, cells and nerves, locally arranged between rectum and vagina, constitutes an incomplete border ventrocranially, Figure 2.2.c. Ventrocaudal border is composed of the serine al body, fibromuscular rather than tendinous and quite unlike the centrum tendineum of the diaphragma.

The only organ is the anorectum, which is constituted by the rectum and the anal canal, Figure 2.2.d. The major part of the posterior pelvic compartment is filled by the anorectum and the perirectal subcompartment, an identical situation happen with the rectal adventitial tissue, which is mainly consisted by adipose tissue subdivided by several connective tissue septa. The nerves of the inferior hypogastric plexus, Figure 2.2.e, are attached to the uterosacral ligament, Figure 2.2.f. The uterosacral ligament is a dense connective tissue running from the edges of the cervix uteri to the region of the sacrospinous ligament., that is directly situated between the rectal fascia and the inferior hypogastric plexus.

The ventral border of the perirectal compartment, which filled by the rectal adventitia including nerves, vessels, and lymph nodes, represents the border between the posterior and middle compartments.

The macroscopic distinction between both muscles is provided by the anococcygeal body [Crocco, 1988; Hamm, 2007].
The important vessels, nerves and lymphatics of the posterior compartment are: superior rectal artery, rectal nerves, rectal lymph nodes, inferior hypogastric plexus, superior hypogastric plexus, common iliac artery and internal iliac artery [Crocco, 1988; Hamm, 2007].

Figure 2.2: In this figure is possible see the anococcygeal body (a), the levator ani muscle (b), the rectovaginal fascia (c), the anorectum (d), the hypogastric plexus (e), the uterosacral ligament (f), the tendinous arch (h), and the perineal membrane (g) (images from Hamm, 2007).

Figure 2.3: Mid-Sagittal MR image of an adult female: The perasacral space is indicated by the arrows and the rectum region by r (image from Hamm, 2007).
2.2.2 - Anterior Compartment

The anterior compartment is constituted by the bladder, Figure 2.1.a, urethra, Figure 2.1.a, pubovesical ligament, Figure 2.4, or cord, which is an ascending course from the pubic bone, Figure 2.1.a, to the neck of the bladder, and the tendinous arch of the pelvic fascia. The bladder is covered by adipose tissue. The fat pad sometimes may be crossed by variable branches from the obturator vessels.

Within the anterior compartment two structures are found that are composed of dense connective tissue: the tendinous arch, Figure 2.2.h, of the pelvic fascia that originates from the pubic bone, Figure 2.4, and that is connected to the pelvic parietal fascia covering the elevator ani muscle on its visceral side and the semicircular fibrous sheath that covers the ventral and lateral wall of the bladder and the urethra.

The fibrous structures of the anterior compartment build up a hammock like construction for bladder and urethra.

An additional fibrous structure can be found to close the hiatus ventrally: a plate of dense connective tissue fills the space between pubic bone and urethral sphincter, thus constituting the perineal membrane, Figure 2.2.g [Crocco, 1988; Hamm, 2007].

![Figure 2.4: Anterior compartment. Axial section (400µm) of a 24-week-old female fetus with the semicircular urethral sheath (indicated by arrows) (x12) (a); Sagittal section (500µm) of a 13 to 14-week-old female fetus with pubovesical ligament (indicated by white spots); Pubic Bone, pbo; Urethra, u; Levator ani muscle, lam (images from Hamm, 2007).](image-url)
The striated muscles of the anterior compartment are the ventral parts of the levator ani muscle, the pubococcygeus and the puborectalis muscle, Figure 2.5. As they are covered by the superior fascia of the pelvic diaphragm, they are clearly separated by the adjacent organs and the external urethral sphincter.

Important vessels, nerves and lymphatics of the anterior compartment are: inferior vesical artery, branches to the ureter, superior vesical artery, vesical lymph nodes, internal iliac lymph nodes, internal iliac artery, inferior hypogastric plexus and paravesical fat pad [Crocco, 1988; Hamm, 2007].

![Figure 2.5: Axial section (400µm) in a female newborn specimen (x4); Urethra - u; Vagina - v; Rectum – r; Puborectalis muscle (arrows) (image from Hamm, 2007).](image)

### 2.2.3 - Middle Compartment

Within the middle compartment the adipose tissue surrounding uterus and vagina. This adipose tissue has regular connective septa tissue and it is continuous with the broad ligaments laterally. The broad ligaments themselves are part of the recto-uterine pouch and consist of colagenous fibers. This tissue has developed to the uterosacral ligaments. Subperitoneally, the middle compartment and its organs about the anterior compartment ventrally. This area is predominated by the dense connective tissue bridge intimately connecting the ventral vaginal wall with the dorsal urethral wall. The border between the middle compartment and the posterior compartment (dorsomedially) is demarcated by the rectovaginal fascia that is composed of dense connective tissue, elastic fibers and
smooth muscle cells. The uterine tubes lie is attached on mesosalpinx, Figure 2.6.a [Crocco, 1988; Hamm, 2007].

The ovaries lie in the ovarian fossa, which are extra peritoneal structures, specially the ureter and the internal iliac vessels as well as the origin of the uterine artery.

The mesometrium, Figure 2.6.b, may be considered the largest part of the broad ligament extending from the pelvic floor to the uterine body enclosing the uterine artery or the connective tissue lying directly beneath the peritoneal covering of the uterus.

The important vessels, nerves and lymphatic of middle compartment are uterine artery and inferior hypogastric plexus. [Crocco, 1988; Hamm, 2007]

Normal Anatomy of the Uterus

The uterus is composed of three distinct anatomic regions, namely the corpus, the isthmus (lower uterine segment) and the cervix, Figure 2.7.

The wall of the uterine corpus differs from that of the cervix in that it mostly consists of myometrium, the strong muscle coat forming the mass of the organ. The uterine cavity is only a thin cleft and is lined by endometrium. Functionally, the endometrium consists of basal and functional layers. In women of reproductive age, the uterus usually is 6-9cm long and weighs 40-60g.

The isthmus of uterus forms the junction between the corpus and cervix, is only about 5mm high and is less muscular than the corpus [Crocco, 1988; Hamm, 2007].

The uterine cervix consists of the supravaginal cervical canal and the vaginal portion that project into the vagina.
The uterus is supplied with blood through the uterine and ovarian arteries. The uterine arteries course to the organ through the cardinal ligaments and are divided into an ascending and a descending branch. Lymphatic drainage from the corpus is through the broad ligament into parametria, Figure 2.8, and iliac lymph nodes.

The normal topography of the uterus is primarily ensured by the parametria, which is a kind of suspension system mainly consisting of connective tissue. The parametria contain large amounts of fatty tissue.

Most of the uterus is covered by peritoneum, that contributes only little support but ensures adequate mobility of the uterus relative to the urinary bladder and rectum, which is necessary to adjust to the variation in bladder filling and especially during pregnancy [Crocco, 1988; Hamm, 2007].

Figure 2.7: Anatomic draft of the uterine cervix (coronal view, image from Hamm, 2007).

Figure 2.8: Anatomic draft, which presents the strong relation between uterine arteries and ureter (indicated by an arrow, image from Hamm, 2007).
Ovaries and Fallopian Tubes

The female adnexal structures are located in the lesser pelvis and include the fallopian tubes, the ovaries and ligamentous attachments, Figure 2.10.

The Fallopian tubes are 8 to 15cm long paired tubular structures at the superior aspect of the broad ligament. They extend from the uterus to the ovaries and are composed of the intramural portion, the isthmus.

The ovaries are typically located in the ovarian fossa close to the lateral pelvic side walls, Figure 2.11. Adult ovaries measure approximately 3-5 cm in length, 1.5-3 cm in width, and 0.5-1.5 cm in thickness. The ovary is encapsulated by thin fibrous layer, the tunica albuginea [Crocco, 1988; Hamm, 2007].

The ovaries contain three ill defined zones: the outer cortex, the highly vascular inner medulla and the hilum. The cortex is predominantly
composed of follicles, corpora lutea, fibroblasts and smooth muscle cells, Figure 2.11 [Crocco, 1988; Hamm, 2007].

Figure 2.11: Ovarian Fossa (image from Hamm, 2007).

The normal fallopian tube contains a small amount of intraluminal fluid that is dispersed within multiple unfolding of the fallopian tube mucosa [Crocco, 1988; Hamm, 2007].

Vagina

The vagina, Figure 2.12, is a fibromuscular sheath like structure connecting the external genitals with the uterus. It is lined with nonkeratinizing squamous epithelium and is 8-12cm long. The epithelium consists of up to 30 cell layers in women of reproductive age but of only a few layers in childhood and after menopause.

The vagina protects the internal genital organs against ascending infections and receives the penis in copulation. The vagina is supplied with blood through the descending branch of the uterine artery [Crocco, 1988; Hamm, 2007].
2.2.4 - Pelvic Girdle

Pelvic Girdle is a basin-shaped ring of bones connecting the vertebral column to the femures and is composed of two coxae (hip) bones. The coxae bone consists of three separate parts: the ilium, the ischium, and the pubis, Figure 2.13.

The adult human bony pelvis is composed of four main elements: the right and left os coxae the sacrum and coccyx. The sacrum and coccyx are parts of axial skeleton and are actually variably fused vertebrae [Crocco, 1988; Hamm, 2007; White, 2005].
2.3 – Physiology and Histology

Physiologically, the pelvic cavity contains different systems, such as: skeletal system, muscular system, cardiovascular system, urinary system, digestive system, and reproductive system.

2.3.1 - Skeletal System

The skeletal system has many functions, which provides support, protection, movement, storage and blood cell production [White, 2005; Seeley, 2004].

<table>
<thead>
<tr>
<th>Table 1: Properties of the skeletal system (from Seeley, 2004 and White, 2005).</th>
</tr>
</thead>
<tbody>
<tr>
<td>The bones are the major supporting tissue of the body, for another side, cartilage provides a firm yet flexible support within certain structures, such as the nose. Ligaments, which are formed by fibrous connective tissue, attach to bones and hold them together.</td>
</tr>
<tr>
<td>The hardness of bones provides organs protection.</td>
</tr>
<tr>
<td>The movement is the other function of the skeletal system and is realized when the contraction of skeletal muscles is observed.</td>
</tr>
<tr>
<td>Skeletal system stores minerals and fats within bone cavities.</td>
</tr>
<tr>
<td>Inside of bones happens the production of blood cells and platelets.</td>
</tr>
</tbody>
</table>

Cartilage comes in three types: hyaline cartilage, fibrocartilage, and elastic cartilage. Hyaline cartilage is the most intimately associated with bone, because most of the bones develop from it. This consists of specialized cells that produce a matrix surrounding the cells, Figure 2.14 [White, 2005; Seeley, 2004].

Histologically, bones are composed by a bone matrix, collagen and hydroxyapatite that provides flexible strength and compression strength, and bone cells, Figure 2.15. The bone cells are osteoblasts, which produce bone matrix and become osteocytes, and osteoclasts. Osteocytes are located in lacunae and are connected to one another through canaliculi. Osteoclasts break down bone and originate from osteochondral progenitor cells [White, 2005; Seeley, 2004].
2.3.2 - Muscular System

The major functional properties of muscle are: contractibility, excitability, extensibility, and elasticity. The contraction of muscle can use the movement of the structures to which it is attached, or it may increase pressure inside hollow organs or vessels. Normally, skeletal muscle contracts as a result of stimulation by nerves and the excitability is the capacity of muscle to respond to a stimulus. Extensibility is the capacity of muscle to stretch to its normal resting length and beyond to a limited degree. The ability of muscle to recoil to its original resting length after it has been stretched is the elasticity [Seeley, 2004].
In pelvic region exists two types of muscles, the skeletal muscle and the smooth muscle [Seeley, 2004].

Table 2: Histology and Physiology of the muscular system (from Seeley, 2004).

<table>
<thead>
<tr>
<th>Features</th>
<th>Skeletal Muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Attached to bones</td>
</tr>
<tr>
<td>Cell shape</td>
<td>Very long and cylindrical (1 mm - 4 cm in length and may extend the entire length of short muscles; 0 - 100 um in diameter)</td>
</tr>
<tr>
<td>Nucleus</td>
<td>Multiple, peripherally located</td>
</tr>
<tr>
<td>Special cell-cell attachments</td>
<td>None</td>
</tr>
<tr>
<td>Striations</td>
<td>Yes</td>
</tr>
<tr>
<td>Control</td>
<td>Voluntary and involuntary (Reflexes)</td>
</tr>
<tr>
<td>Capable of spontaneous contraction</td>
<td>No</td>
</tr>
<tr>
<td>Function</td>
<td>Body movement</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Features</th>
<th>Smooth Muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Walls of hollow organs, blood vessels, eyes, glands, and skin</td>
</tr>
<tr>
<td>Cell shape</td>
<td>Spindle-shaped (15 - 200 um in length and 5-8 um in diameter)</td>
</tr>
<tr>
<td>Nucleus</td>
<td>Single, centrally located</td>
</tr>
<tr>
<td>Special cell-cell attachments</td>
<td>Gap junctions join some visceral smooth muscle cells together</td>
</tr>
<tr>
<td>Striations</td>
<td>No</td>
</tr>
<tr>
<td>Control</td>
<td>Involuntary</td>
</tr>
<tr>
<td>Capable of spontaneous contraction</td>
<td>Yes (some smooth muscle)</td>
</tr>
<tr>
<td>Function</td>
<td>Food Movement Through the digestive tract, emptying of the urinary bladder, regulation of blood vessel diameter, change in pupil size, contraction of many gland ducts, movement of hair, and many other functions.</td>
</tr>
</tbody>
</table>

The Pelvic floor and Perineum

As said in the previous chapter the pelvic region is characterized by a ring of bones, the pelvis, with an inferior opening that is closed by a muscular wall through which the anus and the urogenital openings penetrate. The perineum is the area inferior to the pelvic floor, Figure 2.16 [Seeley, 2004].
Figure 2.16: Muscles of the pelvic floor and perineum – inferior view: male (a) and female (b) (Image from Seeley, 2004).

Table 3: Muscles of pelvic floor and perineum (from Seeley, 2004).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Origin</th>
<th>Insertion</th>
<th>Nerve</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulbospongiosus</td>
<td>Male: central tendon of perineum and median raphe of penis.</td>
<td>Dorsal surface of penis and bulb of penis</td>
<td>Pudendal</td>
<td>Constricts urethra; everts penis</td>
</tr>
<tr>
<td></td>
<td>Female: central tendon of perineum.</td>
<td>Base of clitoris</td>
<td>Pudendak</td>
<td>Everts clitoris</td>
</tr>
<tr>
<td>Coccygeus</td>
<td>Ischial spine</td>
<td>Coccyx</td>
<td>S3 and S4</td>
<td>Elevates and supports pelvic floor</td>
</tr>
<tr>
<td>Ischiocauvernosus</td>
<td>Ischial ramus</td>
<td>Corpus cavernosum</td>
<td>Perineal</td>
<td>Compresses base of penis or clitoris</td>
</tr>
<tr>
<td>Levator ani</td>
<td>Posterior pubis and Ischial spine</td>
<td>Sacrum and coccyx</td>
<td>Fourth Sacral</td>
<td>Elevates anus; supports pelvic viscera</td>
</tr>
<tr>
<td>External anal sphincter</td>
<td>Coccyx</td>
<td>Central tendon of perineum</td>
<td>Fourth sacral pudenda</td>
<td>Keeps orifice of anal canal closed</td>
</tr>
<tr>
<td>External urethral sphincter</td>
<td>Pubic ramus</td>
<td>Median raphe</td>
<td>Pudendal</td>
<td>Constricts urethra</td>
</tr>
<tr>
<td>Transverse perinei</td>
<td>Ischial ramus</td>
<td>Median raphe</td>
<td>Pudendal</td>
<td>Supports pelvic floor</td>
</tr>
<tr>
<td></td>
<td>Ischial ramus</td>
<td>Central perineal</td>
<td>Pudendal</td>
<td>Fixes central tendon</td>
</tr>
</tbody>
</table>

2.3.3 - Blood Vessel Structures in the Pelvic region

The arteries and veins are the most complex vessels of the human body. In the Pelvic region is observed these two types of vessels.

In the arteries, the blood flows from the heart through elastic arteries, muscular arteries, and arterioles to the capillaries. On the other hand, in the
veins the blood returns to the heart from capillaries through venules, small veins and large veins [Seeley, 2004].

The blood vessel walls consist of three relatively distinct layers that are represented in Figure 2.17.

![Diagram of blood vessel histology](image)

Figure 2.17: Histology of a blood vessel – the layers, or tunics, of the blood vessel wall includes the intima, media, and adventitia. A vasa vasorum is a blood vessel that supplies blood to the wall of the blood vessel (image from Seeley, 2004).

The tunica media, Figure 2.17, regulates the amount of blood following through a blood vessel by contraction or relaxation and is separated from the tunica intima by the internal elastic membrane. The tunica intima is a delicate connective tissue. Another layer is the tunica adventitia which is composed of connective tissue, which varies from dense connective tissue that merges with the connective tissue surrounding the blood vessels [Seeley, 2004].

**Arteries of the Pelvis**

The abdominal aorta is divided into two common iliac arteries, the external iliac arteries, which enter the lower limbs, and internal iliac arteries, which
supply the pelvic area. Table 4 indicates all arteries of the pelvic region and
the correspondent tissues supplied [Seeley, 2004].

Table 4: Arteries of the pelvis (from Seeley, 2004).

<table>
<thead>
<tr>
<th>Arteries</th>
<th>Tissues Supplied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Iliac</td>
<td>Pelvis through the branches listed below</td>
</tr>
<tr>
<td></td>
<td>Visceral Branches</td>
</tr>
<tr>
<td>Middle Rectal</td>
<td>Rectum</td>
</tr>
<tr>
<td>Vaginal</td>
<td>Vagina and Uterus</td>
</tr>
<tr>
<td>Uterine</td>
<td>Uterus, vagina, uterine tube, and ovary</td>
</tr>
<tr>
<td></td>
<td>Parietal Branches</td>
</tr>
<tr>
<td>Lateral Sacral</td>
<td>Sacrum</td>
</tr>
<tr>
<td>Superior gluteal</td>
<td>Muscles of the gluteal region</td>
</tr>
<tr>
<td>Obturator</td>
<td>Public region, deep groin muscles, and hip joint</td>
</tr>
<tr>
<td>Internal pudendal</td>
<td>Rectum, external genitalia, and floor of pelvis</td>
</tr>
<tr>
<td>Inferior gluteal</td>
<td>Inferior gluteal region, coccyx and proximal thigh</td>
</tr>
</tbody>
</table>

Figure 2.18: Arteries of the pelvis (image from Seeley, 2004).

Figure 2.19: Branches of the aorta (image from Seeley, 2004).
Veins of the Pelvis

Like the arteries, the internal iliac veins drain the pelvis and join the external iliac veins from the lower limbs to form the common iliac veins, which unite to form the inferior vena cava. The major pelvic veins are listed in Table 5 and illustrated in Figure 2.20 [Seeley, 2004].

Table 5: Veins Draining the Pelvis (from Seeley, 2004).

<table>
<thead>
<tr>
<th>Veins</th>
<th>Tissues Drained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inferior Vena Cava</td>
<td></td>
</tr>
<tr>
<td>Hepatic veins</td>
<td>Liver</td>
</tr>
<tr>
<td>Common iliac</td>
<td></td>
</tr>
<tr>
<td>External iliac</td>
<td>Lower limb</td>
</tr>
<tr>
<td>Internal iliac</td>
<td>Pelvis and its viscera</td>
</tr>
<tr>
<td>Ascending lumbar</td>
<td>Posterior abdominal wall</td>
</tr>
<tr>
<td>Renal</td>
<td>Kidney</td>
</tr>
<tr>
<td>Suprarenal</td>
<td>Adrenal Gland</td>
</tr>
<tr>
<td>Gonadal</td>
<td></td>
</tr>
<tr>
<td>Testibular</td>
<td>Testis</td>
</tr>
<tr>
<td>Ovarian</td>
<td>Ovary</td>
</tr>
<tr>
<td>Phrenic</td>
<td>Diaphragma</td>
</tr>
</tbody>
</table>

Figure 2.20: Inferior vena cava and its tributaries (image from Seeley, 2004).
2.3.4 - Digestive organs of the pelvic cavity

In the large intestine exists the cecum, colon, rectum, and anal canal.

The rectum and anal canal are the components of the digestive system that are localized in the pelvic region.

The function of large intestine is the absorption of water and salts, the secretion of mucus, and the extensive action of microorganisms are involved in the formation of feces [Seeley, 2004].

Histologically, the large intestine is composed by elements that are exposed in Figure 2.21.

Figure 2.21: Histology of large Intestine (image from Seeley, 2004).
Rectum

The rectum is a straight muscular tube. The mucosal lining of the rectum is the simple columnar epithelium, and the muscular tunic is relatively thick compared to the rest of the digestive tract [Seeley, 2004].

Anal Canal

The last 2 – 3 cm of the digestive tract is the anal canal. The smooth muscle layer of the anal canal is even thicker than that of the rectum and forms the internal anal sphincter. The epithelium of the internal anal sphincter is simple columnar and that of the external anal sphincter is stratified squamous [Seeley, 2004].

2.3.5 - Urinary system

The urinary system consists of two kidneys, two ureters, a single urinary bladder, and a single urethra. The ureters extend from the kidneys to the urinary bladder within the pelvic cavity, Figure 2.22 [Seeley, 2004].

Figure 2.22: Ureters and urinary bladder (image from Seeley, 2004).
The bladder has the storage function, whereas the ureters have the conducting function of the urine [Seeley, 2004].

### 2.3.6 - Reproductive System

The female reproductive organs consist of the ovaries, uterine tubes, uterus, vagina, external genital organs, and mammary glands [Seeley, 2004].

The internal reproductive organs of the female are within the pelvis between the urinary bladder and the rectum [Seeley, 2004].

**Ovaries**

Histologically, the ovaries are composed by a visceral peritoneum covering his surface, which is called by the ovarian, or germinal, epithelium, Figure 2.23. This epithelium exists because it was once thought to produce oocytes [Seeley, 2004].

Immediately bellow, the epithelium is a layer of dense fibrous connective tissue called tunica albuginea. Outer part of the ovary is called the cortex, which is the denser layer. The medulla is a looser inner part [Seeley, 2004].

![Histology of ovary (image from Seeley, 2004).](image-url)

*Figure 2.23: Histology of ovary (image from Seeley, 2004).*
The main function of the ovaries is the production and liberation of oocyte.

**Uterine Tubes**

Two uterine tubes can be called fallopian tubes or oviducts.

The wall of each uterine tube consists of three layers, the outer serosa, which is formed by the peritoneum, the middle muscular layer and the inner mucosa. The middle muscular layer consists of longitudinal and circular smooth muscle cells. The inner mucosa consists of a mucous membrane of simple ciliated columnar epithelium. The mucosa provides nutrients for the oocyte, or, if fertilization has occurred, to the developing embryonic mass as it passes through the uterine tube. The ciliated epithelium moves the small amount of fluid [Seeley, 2004].

**Uterus**

The uterus receives the oocyte or, if was fertilized, the ovule and the uterine wall is composed of three layers: perimetrium (serous), myometrium, and endometrium [Seeley, 2004].

The perimetrium covers the uterus. Just deep to the perimetrium the myometrium consists of a thick layer of smooth muscle in the body. The most inner layer of the uterus is the endometrium, which consists of a simple columnar epithelial lining and a connective tissue, the lamina propria.

The endometrium consists of two layers, a thin basal layer and a superficial functional layer. The basal layer is the deepest part of the lamina propria and is continuous with the myometrium.

The thicker superficial functional layer consists of most of the lamina propria and the endothelium and lines the cavity itself. The functional layer changes during the female menstrual cycle. The cervical canal contains cervical mucous glands and acts as a barrier to substances that could pass from the vagina into the uterus [Seeley, 2004].

**Vagina**

The vagina is the female organ of copulation, functioning to receive the penis during intercourse, and it allows menstrual flow and childbirth [Seeley, 2004].
The wall of the vagina consists of an outer muscular layer and an inner mucous membrane. The muscular layer is a smooth muscle that allows the vagina to increase in size to accommodate the penis during the intercourse and to stretch greatly during childbirth. The mucous membrane is the most stratified squamous epithelium that forms a protective surface layer [Seeley, 2004].
## 2.4 – Pathology

At pathological level, the pelvic cavity can be very affected by a large variety of disorders because is constituted by various physiological systems. This work will hold a pathological approach taking into account the different organs.

**Skeletal System**

In the skeletal system, the most affected elements are the joints and arthritis. The inflammation of joints is the most common and best known of the joint disorders [Seeley, 2004; Rubin, 2008].

More than 100 different types of arthritis exist and the classification is often based on the cause and progress of arthritis. Causes include infections agents, metabolic disorders, trauma, and immune disorders [Seeley, 2004; Rubin, 2008].

**Muscular System**

Duchenne’s muscular dystrophy (DMD) is usually identified in children when the parents notice slow motor development [Rubin, 2008].

Typically, muscular weakness begins in the pelvic girdle and causes a waddling gait. Within 3-5 years, muscles of the shoulder girdle become involved and contribute to muscular atrophy and deformity of the skeleton [Rubin, 2008].

Usually, people with DMD are unable to walk by 10-12 years of age, and few live beyond age 20 [Rubin, 2008].

**Digestive System**

In the large intestine hemorrhoids can be seen as the most frequent pathologies [Rubin, 2008].

Hemorrhoids are the inflammation of the hemorrhoidal veins, which supply the anal canal. This causes pain, itching and bleeding around the anus. Treatments include increasing the bulk in the diet, taking sitz baths, and using hydrocortisone suppositories. If the condition is extreme and does not respond to treatments the surgery may be necessary [Rubin, 2008].
The congenital megacolon reflects a segmental abuse of ganglion cells, colon dilation results from a defect in colorectal innervations. The incidence of the disorder is estimated to be 1 on 5000 live births, and 80% of patients are male. The definitive diagnosis of Hirschsprung disease is made on the basis of absence of ganglion cells in a rectal biopsy specimen. This disease is the most common cause of congenital intestinal destruction. In some cases, complete intestinal obstruction requires immediate surgical relief [Rubin, 2008].

Another pathology is the anorectal malformations, which consists in the development defects. The lesions result from arrested development of the caudal region of the gut in the first 6 months of fetal life [Rubin, 2008].

The classification of these anomalies is based on the relation of the terminal bowel to the levator ani muscle [Rubin, 2008]:

1. High or suprarelevator deformities (the bowel ends above the pelvic floor);
2. Intermediate deformities;
3. Low or translevator deformities (bowel ends below the pelvic floor).

In the large intestine can be found a considerable variety of inflammatory diseases but in the occidental societies is the colorectal cancer which is the most common cause of cancer deaths. Most cancers of the colon and rectum arise in adenomatous polyps and so factors associated with development of such polyps are relevant to the genesis of colorectal cancer [Rubin, 2008].

**Urinary System**

The most common urinary tract infection is Cystitis, which is an inflammation of the bladder and it may be acute or chronic. This disease is often seen as a nosocomial infection in hospitalized patients. The risk or Cystitis is increased in females because of the short urethra, especially during pregnancy. Coliform bacteria are the most common cause of Cystitis [Rubin, 2008].

The urinary bladder is the most common site of urinary tract tumors and the majority of bladder tumors occur in older patients (median age 65 years) [Rubin, 2008].
Tumors are often multifocal and can occur in any part of the urinary tract lined by transitional epithelium, from the renal pelvis to the posterior urethra. The surgical treatment is frequently followed by tumor recurrence [Rubin, 2008].

**Reproductive System**

In the reproductive System, the pelvic inflammatory disease (PID) describes an infection of pelvic organs that follows extension of any variety of microorganisms beyond the uterine corpus. The incidence of PID is far greater in sexually promiscuous women than in those who are monogamous. Occasionally, PID is a sequel to post partum endometritis or a complication of endometrial curettage. Complications of PID include [Rubin, 2008]:

1. Rupture of a tuboovarian abscess;
2. Infertility from scarring of the healed tubal plicae;
3. Increased rates of ectopic pregnancy;
4. Intestinal obstruction from fibrous bands and adhesions.

Leiomyoma is the most common tumor of the female genital tract, which occur in 75% of women over 30 years of age. Grossly, leiomyomas are firm, pale gray, whorled, and without encapsulation. They range from 1 mm to more than 30 cm in diameter, Figure 2.24, [Rubin, 2008].
Most leiomyomas are intramural, but some are submucosal, subserosal or pedunculated, as shown in Figure 2.24.

Leiomyomas displays low mitotic activity and have little or no malignant potential [Rubin, 2008].
2.5 – Summary

The pelvic floor is subdivided according to a clinical discern: an anterior, middle and a posterior compartment.

The anterior compartment is constituted by the bladder, urethra, pubovisceral ligament, pubic bone, urethral sphincter, and the tendinous arch of the pelvic fascia. Other structures that can happen are striated muscle like levator ani muscle, the pubococcygens and the puborectalis muscle (ventral parts). Important vessels, nerves and lymphatics of the anterior compartment are: inferior vesical artery, branches to the ureter, superior vesical artery, vesical lymph nodes, internal iliac lymph nodes, internal iliac artery, inferior hypogastric plexus and paravesical fat pad.

The middle compartment presents the uterus, vagina, ovaries, ovarian fossa, uterine artery, and inferior hypogastric plexus.

In the posterior compartment can be found skeletal elements (sacrum and the coccyx), muscular elements (levator ani muscle, pubococcygeus muscles, anal sphincter), digestive system (the only organ is the anorectum), and ligaments (uterosacral ligament, sacrospinous ligament). The important vessels, nerves and lymphatics are superior rectal artery, rectal nerves, rectal lymph nodes, inferior hypogastric plexus, superior hypogastric plexus, common iliac artery and internal iliaca cutery.

All this compartments are protected and supported by the pelvic girdle.

Histologically the skeletal system is composed by the bone cells (osteoblasts, osteocytes and osteoclasts) and bone matrix (collagen and hydroxyapatite).

Muscular system has a large variety of the functional properties, such as: contractibility, excitability, exentesibility, and elasticity.

The major arteries of the pelvis are the two common iliac arteries, the external iliac arteries, and internal iliac arteries. The arteries have an oxygen supply function on tissues that are localized in this region.

The internal iliac veins drain the pelvis and join the external iliac veins from the lower limbs to form the common iliac veins.

The function of large intestine is absorption of water and salts the secretion of mucus, and the extensive action of microorganisms are involved in the formation of feces.
In the urinary system the bladder has the storage function and the ureters have the conduct function the uterine.

The ovaries are reproductive organs that produce oocytes, whereas the uterine tubes are responsible for the conduction of the oocyte, if fertilization has occurred the mucosa of uterine tubes provides nutrients for the oocyte.

The uterus receives the oocyte and if fertilization has occurred the uterus is responsible for the nutrition of oocyte.
III – Medical Imaging
3.1 – Introduction

Biological signals are transformed into images via medical imaging modalities.

In this chapter, will be realized a presentation of medical imaging history. This will allow knowing the origin and the development of medical imaging over the years, which is very important to understand the main facts and aspects that happened to make the evolution of medical imaging possible.

After that, a large variety of methods to obtain the medical imaging will be presented. The explanation of methods will facilitate the distinction of the existing solutions taking into account the features under study.

Distinct methods have different characteristics and are obtained in diverse conditions. Therefore, the knowledge on the most common methods becomes essential to know what the best solution is to realize a particular imaging processing task.

Special emphasis, will be done on magnetic resonance imaging, since this research project will be based on this kind of imaging modality.
3.2 – History of Medical Imaging

Radiograph was the first published medical image of the hand of Wilhelm Conrad Roentgen’s wife in December of 1895. This discovery would have a profound impact in medicine. The first clinical use of x-rays occurred only two months later, in February of 1896. The static and dynamic techniques were then developed. A static technique refers to an image taken at a single point in time. A dynamic technique refers to a series of images acquired over time. Planar radiographs, for many decades, were the only medical images being produced. Radiography was extended into transmission computed tomography (CT) or cross-sectional imaging. The first true CT scanner was produced by Godfrey Hounsfield in 1972. Godfrey used mathematical method for image reconstruction developed a decade earlier by Allan Cormack of the United States. Many radiologists consider CT scanning to be the most important development in medical since Roentgen’s original discovery.

Nuclear medicine arose from the discovery of radioactivity by Antoine Henri Becquerel in 1896. Radionuclides were used in cancer therapy rather than in medical imaging.

George the Hevesy, in 1923, introduced a concept of using radioactive tracers to study physiology.

Early studies with radiotracer used conventional non imaging radiation detectors to determine the radioactivity in various body regions in a rough manner. The first imaging system in nuclear medicine, the rectilinear scanner was started developed by Benedict Cassen at UCLA, in 1949. Technetium – 99m, which is the element of the most commonly used radionuclide in nuclear medicine, was discovered in 1937 by Perrier and Emilio Segre.

Ultrasond technology progressed through the 1960s from simple A-mode and B-mode scans to today’s M-mode and Doppler two dimensional (2-D) and even three-dimensional (3-D) systems.

Nuclear Magnetic Resonance was first described by Felix Bloch and Edward Purcell, they shared the 1952 Nobel Prize in Physics. In 1971, Raymond Damadian published a paper suggesting the use of magnetic resonance in medical imaging [Prince, 2005].
3.3 – Imaging Systems

The detection of different physical signals arises from four processes: transmission of x-rays through the body (in projection radiography and CT), emission of gamma rays from radiotracers in the body (in nuclear medicine), reflection of ultrasonic waves within the body (in ultrasound imaging), and precession of spin systems in a large magnetic field (in magnetic resonance imaging).

The imaging systems have a large variety of modalities. Projection radiography includes the following ones:

- Routine diagnostic radiography: chest x-rays, fluoroscopy, mammography, and motion tomography;
- Digital radiography: includes all the scans in routine radiography, but with images that are recorded digitally;
- Angiography (the systems are specialized for imaging the body’s blood arteries and vessels): angiography and angiocardiography;
- Neuroradiology: specialized x-ray systems for precision studies;
- Mobile x-ray systems: designed for operating rooms or emergency vehicles.

Computed Tomography uses x-rays, which traveling in a 3-D cone beam, restricted in their geometric spread. They are collimated to travel within an approximate 2-D “fan beam”. Tissues create shadows in the x-ray beam that culminate in a 2-D cross-section of the body and a large number of small detectors are detected and collected for many angular orientations. These measurements are called projections and an image of the cross-section is computed from these projections.

Projection CT includes the following modalities:

- Single-slice CT (standard);
- Helical CT;
- Multi-slice CT.

In helical CT, the x-ray tube and detectors continuously rotate around in a large circle, at the same time the patient is moved in a continuous motion through the circle’s center.
This technique is important due to the ability to rapidly acquire 3-D data rapidly (scan of the whole body in less than a minute).

The multi-slice CT has several rows of detectors used to rapidly gather a cone of x-ray data, comprising a 2-D projection of the 3-D patient.

Nuclear medicine imaging can only be made with an appropriate introduction of radioactive substances. These drugs are labeled as radionuclides that emit gamma rays and radionuclides are called radiotracers.

Nuclear medicine imaging is an example of functional imaging method, whereas standard CT and MRI are anatomical or structural imaging methods.

Nuclear medicine includes:

- Conventional radionuclides imaging or scintigraphy - utilizes a special 2-D gamma ray scintillation detector.
- Single-photon emission computed tomography (SPECT) – makes use of a special 2-D gamma ray scintillation detector.
- Positron emission tomography (PET).

The special 2-D gamma ray scintillation detector is called Anger camera, which is designed to detect single x-rays or gamma rays.

Conventional radionuclide imaging combines the effects of emission with the effects of attenuation of the rays by intervening body tissues. This modality produces images that are 2-D projections of 3-D distribution of radiotracers.

SPECT produce images of slices within the body by rotating the Anger camera around the body and using CT methods to reconstruct images.

In PET, radionuclide decay produces a positron, which immediately annihilates to produce two gamma rays flying off in opposite directions.

Ultrasound imaging generates repetitive bursts of high-frequency sound using electrical-to-acoustical transducers.

Ultrasound imaging systems offer several imaging modes:

- A-mode imaging: generates a one-dimensional waveform and can provide very detailed information about rapid or subtle motion.
- B-mode imaging: ordinary cross-sectional anatomical imaging and can give rise to images with different appearances.
- M-mode imaging: generates a succession of A-mode signals and the image is not anatomical but is important for measuring time varying.

- Doppler imaging: uses the property of frequency or phase shift caused by moving objects to generate images that are color coded by their motion.

Magnetic Resonance (MR) creates images using the property of nuclear magnetic resonance. The nucleus of the hydrogen atom in the presence of a strong magnetic field tends to align itself with the field. The human body includes a vast number of hydrogen atoms and alignment results in a net magnetization of the body.

The most general categories of operation are the following:

- Standard MR: time series of different excitation pulses.

- Echo-planar imaging (EPI): utilizes specialized apparatus to generate images in real time.

- Magnetic resonance spectroscopic imaging: images other nuclei besides the hydrogen atom.

- Functional MRI (fMRI): uses oxygenation sensitive pulse sequences to image blood oxygenation in the brain [Prince, 2005].
3.4 – Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is a noninvasive medical imaging technique. The tremendous clinical utility of MRI is due to the great variety of mechanisms that can be exploited to create image contrast. If magnetic resonance images were restricted to water density, MRI would be considerably less useful, since most tissues would appear identical. Fortunately, many distinct MRI contrast mechanisms can be employed to distinguish different tissues and disease processes.

3.4.1 - Fundamentals of MRI

Magnetic resonance imaging exploits the existence of induced nuclear magnetism in the patient. Most commonly protons ($^1$H) are imaged although carbon ($^{13}$C), phosphorous ($^{31}$P), sodium ($^{23}$Na), and Fluorine ($^{19}$F) are also of significant interest. Field strength is usually to be of 0.2 and 1.5T, but for spectroscopic and functional imaging is necessary higher field strength.

The ratio of the induced magnetization to the applied fields is only $4 \times 10^{-9}$.

The key idea is to measure the moment while it oscillates in a plane perpendicular to a static field [Bloch et al, 1946; F. Bloch, 1946]. The torque always points perpendicular to the magnetization and causes the spins to oscillate in a perpendicular plane to the static field. The frequency of rotation $\omega_0$ is proportional to the field:

$$\omega_0 = -\gamma B_0 \quad (3.1)$$

where $\gamma$, the gyromagnetic ratio, is a constant specific to the nucleus, and $B_0$ is the magnetic field strength.

A complex molecule is placed in a highly uniform magnetic field, is produced microscopic field variations within the molecule so that geometrically isolated nuclei rotate about distinct fields. Magnetic environment produces a peak in the spectra of the received signal.

Nuclear magnetic resonance signal from a human is due predominantly to water protons. Since these protons exist in identical magnetic environments, they all resonance at the same frequency.

The MR signal is simply proportional to the volume water. The most effective non-uniform field is a linear gradient where the field and the resulting frequencies vary linearly with distance along the object. Fourier analysis of the signal obtains a map of the spatial distribution of spins, k-space analysis of MRI [Twieg, 1983; Ljunggren, 1983].
**K-space Analysis of Data Acquisition**

In MRI, is received a volume integral from an array of oscillators. During signal reception, the applied magnetic field points in the $z$ direction. Hence a spin at position $r=(x,y,z)$ has a unique phase $\theta$ that describes its angle relative to their axis in the $xy$ plane.

\[ \theta(r,t) = -\gamma \int_0^t B_z(r,\tau) d\tau \]  \hspace{1cm} (3.2)

Where $B_z(r,t)$ is the $z$ component of the instantaneous, local magnetic flux density.

A coil large enough to receive a time-varying flux uniformly from the entire volume produces:

\[ s(t) = \frac{d}{dt} \int M(r) e^{-j\theta(r,t)} dr \]  \hspace{1cm} (3.3)

$M(r)$ represents the equilibrium moment density at each point $r$. In general, gradient is $(xG_x + yG_y + zG_z)$, these gradient field components can vary with time, so the total $z$ field is

\[ B_z(r,t) = B_0 + G(t)r \]  \hspace{1cm} (3.4)

In the presence of this general time-varying gradient, the received signal is

\[ s(t) = \frac{d}{dt} \int e^{-j\theta} M(r) e^{-jG(t)r} dr \]  \hspace{1cm} (3.5)

The center frequency $\gamma B_0$ is always much larger than the bandwidth of the signal. Hence the derivative operation is approximately equivalent to multiplication by $-i\omega_0$. 
Then can now identify as the spatial Fourier transform of $M(r)$ evaluated at $k(t)$. That is, $S(t)$ scans the spatial frequencies of the function $M(r)$. This can be written explicitly as

$$S(i)an(k(i))$$ (3.6)

where $m(k)$ is the three-dimensional Fourier transform of the object distribution $M(r)$. Thus one can view MRI with linear gradients as a “scan” of k-space or the spatial Fourier transform of the image. After the desired portion of k-space be scanned, the image $M(r)$ is reconstructed using an inverse Fourier Transform [Bronzino, 2000].

2D Imaging

The two-dimensional Fourier transform imaging is to scan through k-space along several horizontal lines covering a rectilinear grid in 2D k-space. The horizontal grid lines are acquired using 128 to 256 excitations separated by time TR. The horizontal line scans through k-space are offset in $k_y$, by a variable area $y$-gradient are called pulse, which happens before data acquisition starts. For each $k_y$ phase signal is acquired while scanning horizontally with a constant $x$ gradient [Bronzino, 2000].

Resolution and Field of View

The fundamental image characteristics of resolution and field of view are the completely determined by the characteristics of the k-space scan. The extent of the coverage of k-space determines the resolution of the reconstructed image.

Diffraction limits the resolution and the resolution is limited to the wavelength divided by the angle subtended by the receiver aperture. The ultimate resolution is approximately the wavelength itself, but this is true for imaging systems based on optics like ultrasound, and x-rays. MRI is the only imaging system where the resolution is independent of the wavelength, because no attempt is made to focus the radiation pattern to the individual pixel or voxel (volume element). In this technique, the wavelength is often of several meters. The gradients create spatially varying magnetic fields and individual pixels emit distinctive waveform signatures. These signals are
decoded and assigned to unique positions. The problem is isolating the signals from two transmitting antenna towers separated by much less than a wavelength so is possible to distinguish the two signals if the two antennas transmit different frequencies. Both signals are received with a wide-angle antenna and then distinguish the signals through frequency-selective filtering [Bronzino, 2000].

**Noise sources**

The dominant noise source is due to thermally generated currents within the conductive tissues of the body. These currents create a time-varying flux which induces noise voltages in the receiver coil. Other noise sources include the thermal noise from the antenna and from the first amplifier. These systems are designed so that the noise is negligible compared with the noise from the patient.

The noise received is determined by the total volume acquired by the antenna pattern $V_n$ (noise volume based on the distribution of thermally generated currents) and the effective resistivity and temperature of the conductive tissue. The standard deviation of the noise from conductive tissue varies linearly with $B_0$ [Hoult, 1979].

The noise is filtered by integration over the total acquisition time $T_{acq}$, which effectively attenuates the noise standard deviation [Bronzino, 2000].

**Contrast Mechanisms**

The most important contrast mechanisms exploit relaxation of the magnetization with the two types of relaxations that are termed spin-lattice relaxation. The first type is characterized by a relaxation time $T_1$, and the other spin-spin relaxation, characterized by a relaxation time $T_2$.

Spin-lattice relaxation describes the rate of recovery of the z component of magnetization toward equilibrium after it has been disturbed by pulses. The recovery is given by

$$M_z(t) = M_0(1 - e^{-t/T_1}) + M_z(0)e^{-t/T_1}$$

(3.7)
where \( M_0 \) is the equilibrium magnetization. Differences in the \( T_1 \) time constant can be used to produce image contrast by exciting all magnetization and then imaging before full recovery has been achieved. This is illustrated on the left in Figure 3.1. The plots show the recovery of two different \( T_1 \) components. The short \( T_1 \) component recovers faster and produces more signals.

Figure 3.1: The two primary MRI contrast mechanisms, \( T_1 \) and \( T_2 \). \( T_1 \), illustrated on the left, describes the rate at which the equilibrium magnetization is restored after it has been disturbed. \( T_1 \) contrast is produced by imaging before full recovery has been obtained. \( T_2 \), illustrated on the right, describes the rate at which the MRI signal decays after it has been created. \( T_2 \) contrast is produced by delaying data acquisition, so shorter \( T_2 \) components produce an inferior signal (from [Bronzino, 2000]).

Spin-spin relaxation describes the rate at which the NMR signal decays after it has been created. The signal is proportional to the transverse magnetization and is given by:

\[
M_{xy}(t) = M_{xy}(0)e^{-t/T_2} \tag{3.8}
\]

In addition to the intrinsic tissue contrast, artificial MRI contrast agents also can be introduced and are usually administered intravenously or orally. The most popular agents decrease both \( T_1 \) e \( T_2 \) [Bronzino, 2000].
Hardware/ Instrumentation

In this section the basic components and the operating principles of MRI scanners will be described.

The main components of the MRI scanner are its magnet and radiofrequency system [Novelline, 2004].

3.4.2 - Fundamentals of MRI Instrumentation

There are three types of magnetic fields (static fields ($B_2$), gradient fields and a radiofrequency (RF) fields ($B_1$)) that are required in MRI scanners. Usually it is also necessary to use coils or magnets that produce shimming fields to enhance the spatial uniformity of the static field $B_0$. Most MRI hardware engineering is concerned with producing and controlling these various forms of magnetic fields [Bronzino, 2000].

Static Field Magnets

The main field magnet is required to produce an intense and highly uniform, static magnetic field over the entire region to be imaged [Thomas, 1993]. This field must be extremely uniform in space and constant in time. The spatial variation of it main field of a whole-body scanner must be less than about 1 to 10 parts per million (ppm) over a region approximately 40cm in diameter. The temporal drift of the field strength is normally required to less than 0.1 ppm/h.

The units of the magnetic field strength are the gauss (G) and the tesla (T), which is more recently adopted unit, but is a part of the SI system of units and, for this reason, is generally preferred. The tesla is a much larger unit than the gauss – 1T corresponds to 10000G. The range of the static magnetic fields of modern MRI scanners is 0.5 to 1.5 T. However, useful scanners have been built using the entire range from 0.02 to 8T. The signal to noise ratio (SNR) is one of the key parameters that determine the performance capabilities of a scanner, because is the ratio of the NMR signal voltage to the ever-present noise voltages that arise within the patient and within the electronic components of the receiving system. Magnetic fields are produced by using either electric currents or permanently magnetized materials as sources [Bronzino, 2000].
Figure 3.2: Digital and analog domains for MRI imaging. MRI involves the flow of data and system commands between these two domains (from [Schenck and Leue, 1991]).

Figure 3.3: Block diagram for an MRI scanner. A general-purpose computer is used to generate the commands that control the pulse sequence and to process data during MR scanning (from [Schenck and Leue, 1991]).

To produce the highly uniform magnetic field required for MRI, it is necessary to more or less surround the patient with a magnet. The main field magnet is the most important determinant of the cost, performance, and appearance of an MRI scanner. The main magnets are subdivided in
four classes: the permanent magnets, electromagnets, resistive magnets, and superconducting magnets. All these magnets have been used in MRI scanners [Schenck and Leue, 1991].

**Permanent Magnets and Electromagnets**

The permanent magnets and electromagnets use magnetized materials to produce the field. In a permanent magnet, the patient is placed in the gap between a pair of permanently magnetized pole faces. With electromagnets the pole faces are made of soft magnetic materials, which become magnetized only when subjected to the influence of electric current coils that are wound around them. Electromagnets require the use of an external power supply, but permanent magnets do not [Bronzino, 2000].

For permanent magnets and electromagnets the magnetic circuit is completed by use of a soft iron yoke connecting the pole faces to one another. The materials of the permanent magnets for use in MRI scanners include high-carbon iron, alloys such as Alnico, ceramics such as barium ferrite, and rare earth alloys such as samarium cobalt [Bronzino, 2000].

The advantages of permanent magnets are:

- Production of a relatively small fringing field;
- Do not require power supplies.

They tend to be very heavy (up 100 ton) and can produce relatively low fields, on the order of 0.3 T or less.

Figure 3.4: Permanent magnet. The figure shows a schematic cross-section of a typical permanent magnet configuration. Electromagnets have a similar construction but are energized by current-carrying coils wound around the iron yoke. Soft magnetic shims are used to enhance the homogeneity of the field. (from [Schenck and Leue, 1991])
They are also subject to temporal field drift caused by temperature changes. If the pole faces are made from an electrically conducting material, eddy currents induced in the pole faces by the pulsed gradient fields can limit performance as well. For to make lighter-weight permanent magnet scanners, an alloy of neodymium, boron, and iron was used recently [Schenck and Leue, 1991].

**Resistive Magnets**

In the late 1970s and early 1980s, the first whole-body was manufactured. This used four to six large coils of cooper or aluminum wire surrounding the patient. These coils are energized by powerful (40 to 100kW) direct-current (dc) power supplies. For prevent overheating is necessary the use of cooling water flowing through the coils. The heat dissipation increases rapidly with field strength, and it is not feasible to build resistive magnets operating at fields much higher than 0.15 to 0.3T. The resistive magnets are seldom used except for very low field strength (0.02 to 0.06 T) applications [Bronzino, 2000].

**Superconducting Magnets**

The use of cryogenically superconducting magnets [Wilson, 1983] has been the most satisfactory solution to the problem of producing the static magnet field for MRI scanners. The property of exhibiting absolutely no electrical resistance near absolute zero has been known as an exotic property of same materials since 1911. These materials retain the ability to carry loss-free electric currents in very high fields [Schenck and Leue, 1991].

Figure 3.5 illustrates the construction of a typical superconducting whole-body magnet. Six coils of superconducting wire are connected in a series and carry an intense current. A current of 200A produces 1.5T magnetic field at the magnet’s center. The coils have a diameter of about 1.3m, and the total length of wire is about 65km. If the magnet wire has no such flaws, the magnet can be operated in the constant mode. A constant persistent current flow indefinitely so long as the temperature of the coils is maintained below the superconducting transition temperature. This temperature is about 10K for niobium-titanium wire. Many magnets now make use of cryogenic refrigerators that reduce or eliminate the need for refilling the liquid helium reservoir.
Magnets have operated for years completely disconnected from power supplies and maintained their magnetic field constant to within a few parts per million. Superconducting magnets have become the most widely used source of the main magnetic fields for MRI scanners [Bronzino, 2000].

**Magnetic Field Homogeneity**

The manufacturing tolerances and field perturbations caused by extraneous magnetic field sources, such as steel girders in the building surrounding the magnet that produce additional in homogeneity in the imaging region. These field imperfections are reduced by the use of shimming fields. One approach, uses additional coils which are designed to produce a magnetic field corresponding to a particular term in the spherical harmonic expansion. The magnetic field is carefully mapped, and the currents in the shim coils are adjusted to canceling the terms in the harmonic expansion to some prescribe high order – active shimming. The alternative approach utilizes small permanent magnets that are placed at the proper locations along the inner walls of the magnet bore to cancel the contaminating fields – passive shimming [Bronzino, 2000].
Fringing Fields

A strong magnetic field is produced by a powerful magnet in the region surrounding it as well as in its interior. The fringing field can produce undesirable effects such as erasing magnetic tapes. It is also a potential hazard to people with implanted medical devices.

Radiofrequency Coils

The radiofrequency coils are used for two essential purposes: transmitting and receiving signals at the resonant frequency of the protons within the patient [Schenck, 1993]. In the range of field strengths currently used in whole body scanners, 0.02 to 4T, the operating frequency ranges from 0.85 to 170.03 MHz. For the commonly used 1.5T scanners, the operating frequency is 63.86MHz.

Ideally, the radiofrequency field is perpendicular to the static field, which is in the z direction. The radiofrequency field can be linearly polarized in either the x or y directions.

The most efficient RF field results from quadrature excitation, which requires a coil that is capable of producing simultaneous x and y fields with a 90 degree phase shift between them.

There are three classes of radiofrequency coils: body coils, head coils, and surface coils. Head and body coils are enough to surround the region being imaged. Body coils have a large enough diameter to entirely surround the patient’s body (50 to 60cm). Head coils are designed only for head imaging (28cm). Surface coils are smaller coils designed to image a restricted region of the patient’s anatomy. They come in a wide variety of shapes and sizes [Bronzino, 2000].
3.5 – Summary

Medical Imaging relies on noninvasive techniques to image body structures and function.

Each technique or method has a large variety of different imaging modalities.

The main imaging modalities are projection radiography, computed tomography, nuclear medicine, ultrasound imaging, and magnetic resonance imaging.

The signal of interest is defined by the modality and specific imaging parameters.

In general, MRI has the following advantages:

- MRI does not use any other type of ionizing radiation. Alternatively, powerful magnetic fields and radio frequency are used to acquire images, so MRI provides a safer imaging.

- MRI has the ability to change the imaging plane by choosing radio frequency pulse, which also called ‘slice selection’. Therefore the patient’s body does not need to be moved during the MRI scan.

- MRI has the ability to adjust the contrast of scans by changing the radio waves and magnetic fields, different structures and tissues can be highlighted.

MRI is not applicable for some patients who have received certain types of surgical clips, metallic fragments, cardiac monitors, or pacemakers.

Radiologists are trained to look for specific patterns, defined by the modality, explicit imaging parameters and differences in the expected signal in health and disease.
IV – Image Processing and Analysis
4.1 – Introduction

The theme of the work is focused on analysis and image processing. This presented chapter is divided into 4 main sections. This starts with the description of the method that realizes the digitalization of the images, then will display one of the software that can be used to processing and analysis the medical images. Later can be seen a description of the methods of image enhancement.

The method that realizes the digitalization is an important part of this chapter because it becomes possible to know the characteristics of data that will be processed.

A brief overview of the software that can be used must be made to demonstrate what the tools used during the work.

Enhancement is one of the major processing steps for to make more efficient the completion of the analysis. One of the stages of image analysis to be described is the segmentation. In order to define and characterize the segmentation is realized a description of the techniques used to objects segmentations.
4.2 – Digital Image

The main processes involved in creating a digital image from an optical image are sampling and quantization.

The sampling (4.1) is the process that defines time instants or locations (4.4) where the image values are recorded (4.2). This process also can be denominated by discretization [Gonzalez, 2008].

The sampling operation is represented by:

\[ f^*(t, z) = f(t, z) * s_{\Delta T \Delta z}(t, z) \]  \hspace{1cm} (4.1)

\[ f(m, n) = f^*(t, z) \]  \hspace{1cm} (4.2)

\[ f(t, z) \]  \hspace{1cm} (4.3)

\[ s_{\Delta T \Delta z}(t, z) = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} \delta(t - m\Delta T, z - n\Delta z) \]  \hspace{1cm} (4.4)

The quantization is the discretization of the continuous image intensity in a finite number of levels. The number of picture elements (pixels) used to represent the image and the number of quantization levels used to represent pixel intensity is the main characteristics of an image [Gonzalez, 2008; Gonzalez, 2004].

For defined an image is necessary two-dimensional function, \( f(x, y) \), where \( x \) and \( y \) are spatial coordinates. The amplitude of \( f \) is called intensity or gray level. A digital image is composed by a finite number of elements, each of which has a particular location and value. Pixels word is used to denote the elements of a digital image.

Image analysis is the area of image processing and computer vision.

In computer vision has three types of computerized processes:

- Low-level processes – primitive operations such as image processing to reduce noise, contrast enhancement, and image sharpening.
- Mid-level processes – segmentation (portioning an image into objects), description of those objects, and classification (recognition) of individual objects. Outputs are attributes extracted from the input image.
- Higher-level – performing the cognitive functions normally associated with human vision “making sense” of an ensemble of recognized objects [Gonzalez, 2004].

Color images are constituted by a combination of individual 2D images. The basic system is the RGB color system, which consists in three individual component images (red, green and blue). Many of the techniques developed for monochrome images can be extended to color images [Gonzalez, 2008].

In the MATLAB a digital image can be represented by a matrix:

\[
f = \begin{bmatrix}
f(1,1) & \cdots & f(1,N) \\
\vdots & \ddots & \vdots \\
\vdots & \ddots & \vdots \\
f(M,1) & \cdots & f(M,N)
\end{bmatrix}
\]  

(4.5)

\(M\) – Represents the number of lines;

\(N\) – Represents the number of columns. [Gonzalez, 2004]
4.3 – MATLAB and the Image Processing

MATLAB is one of the software that can be used for realized the processing and medical image analysis.

MATLAB is a language for technical computing, which integrates computation, visualization, and programming. MATLAB is a high performance language that use environment where problems and solutions are expressed in familiar mathematical rotation.

Image processing Toolbox of the MATLAB uses: Math and computation, algorithm development, data acquisition, modeling, simulation, data analysis, visualization, scientific and engineering graphics, application development, etc.

The basic data element that is used in MATLAB is an array that does not require dimensioning. MATLAB is the computational tool for research, development, and analysis, which is complemented by a family of application specific solutions called toolboxes.
The Image Processing Toolbox is a collection of functions that have the capacity for the solution of digital image processing problems.

The MATLAB software was used in the creation of the enhancement algorithms [Gonzalez, 2004].
4.4 - Image Processing and Analysis

Computational vision is the capacity to describe or analyze digital images. For human, this process is relatively easy, because of his powerful vision system.

The image processing and the computational vision are constituted by the following areas:

- Image enhancement and restoration;
- Image segmentation;
- Image characterization;
- Image registration;
- Image classification.

In conclusion, the computer vision is subdivided in two steps: the analysis and recognition [Gonzalez, 2004].
4.4.1 - Image Enhancement

Enhancement techniques basically are procedures designed to manipulate an image in order to take advantage of the psychophysical aspects of the human visual system.

Image enhancement can be obtained with a variety of operations. In the magnetic resonance imaging the result is an image with gray scale pixels.

Image enhancement deals with the improvement of visual appearance of the scene for better contrast and visibility of features of interest to be used by either a machine vision system or a human observer.

The enhancement system has all the following functions:
- Attenuate the effects of sub-sampling;
- Attenuate quantization effects;
- Remove noise and simultaneously preserve edges and image details;
- Avoid aliasing effects;
- Attenuate the blockiness effect;
- Improve image contrast;
- Enhancement special features to be more easily detected by a machine or a human observer.

For medical images, noise is always involved in the signal due to the limitations of imaging hardware and protocols. Noise reduction is one the most important objectives for medical image processing. Almost all model-free segmentation methods are sensitive to noise in images. Mode-based methods are more robust, too much noise still can lead to an unsatisfying segmentation result.

Usually, an image is smoothed to remove certain noise by applying a convolution operation onto the image with a certain smoothing kernel.

Image enhancement using local operators is a kind of operation that is also called neighborhood processing or spatial filtering [Gonzalez, 2008; Gonzalez, 2004].

Spatial filter

For filter MR images can be used linear spatial filtering and nonlinear spatial filtering. Linear spatial filter uses the spatial convolution and is characterized by a kernel.
The average filters or arithmetic mean filters performs as a result an image smoothing [Gonzalez, 2004; Gonzalez, 2008].

\[
G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}
\]

(4.6)

Gaussian filters are a class of smoothing filters where the kernel values have 2D Gaussian Shape. In image enhancement for to realize noise reduction in the magnetic resonance images is necessary utilize a Gaussian filter.

Usually, an image is smoothed to remove certain noise by applying a convolution operation onto the image with a Gaussian convolution kernel. Gaussian kernel is defined by equation:

In digital image processing the Gaussian kernel is expressed in a discrete form with a certain size. The kernel is symmetric in both vertical and horizontal directions, and the sum of all kernel elements equals to 1, which guarantee the stability of convolution operation on image data.
The Gaussian smoothing method is that it also tends to blur the sharp boundaries in the image while removing the noise. Even smoothing does not obliterate boundaries of the image. It tends to distort the fine structure of the image and thereby changes subtle aspects of the anatomical shapes [Feissel, 1984].

An anisotropic diffusion algorithm is used to reduce noise of MRI scans without removing significant features of edges of the structure.

This algorithm was proposed by Perona and Malik in 1990 [Perona, 1990]. In this method a gaussian smoothed image can be taken as a solution to heat diffusion equation with respect to a certain time value $t$. The heat diffusion equation is in the form of

$$\frac{\partial g(x,y,t)}{\partial t} = \nabla \nabla g(x,y)$$

(4.7)

$$f(x,y) = g(x,y,0)$$

(4.8)

$$g(x,y,t) = G(\sqrt{2t}) \otimes f(x,y)$$

(4.9)

where $f(x,y)$ is an input image, $g(x,y)$ is a Gaussian smoothed image with a parameter of $t$, and $G$ is a Gaussian kernel. The conductance term is included in the anisotropic diffusion. The conductance depends on the differential results of the images. With this term is possible controller the smoothing.

$$c(\nabla g(x,y,t)) = e^{\frac{\|\nabla g(x,y,t)\|^2}{2k^2}}$$

(4.10)

In this equation $c$ is the variable conductance term. If the edges of structure in the smoothed images have higher gradient magnitude than of non-edge region, the conductance will be reduced, and the smoothing effect will be limited. The time-dependant gradient magnitude, the conductance is depends on $k$, which is the conductance parameter. This parameter controls the sensitivity of the process to the structure edge.
In the anisotropic diffusion filter, the t and k are the control parameters, while σ controls the Gaussian smooth kernel. In this process is necessary an iteration number, which is need to define when is used the anisotropic smoothing [Perona, 1990].

Non linear spatial filters don’t use the spatial convolution, an example is median filter. This filter is utilized when is observed salt and pepper noise. When is realized this filter the pixel values contained in the predefined neighborhood are ordered, and choice the middle value.

![Input Image and Median Filter](image)

Figure 4.5: The result of a median filter in an image with salt and pepper noise (Image from Mendonça, 2010).

The gradient or first derivate is calculated from smoothed MRI scans. The intensity of each pixel or voxel changes by providing two types of information, the magnitude and orientation. The magnitude of gradient tells how quickly the intensity changes. The direction tells in which orientation the intensity changes most rapidly. The sharp intensity changes are often across the edges of structures, so gradient magnitude is useful for extracting all of the possible structure edges.

The gradient function can be expressed as a continuous function with two variables.

\[
\nabla f = \text{grad}(f) = \begin{bmatrix}
\frac{\partial f}{\partial x} \\
\frac{\partial f}{\partial y}
\end{bmatrix}
\]

(4.11)

Elisa Maria Lamego Barroso
\[
\begin{align*}
M(x, y) &= \text{mag}(\nabla f) = \sqrt{g_x^2 + g_y^2} \\
\theta(x, y) &= \arctan\left(\frac{g_x}{g_y}\right)
\end{align*}
\]  \quad (4.12)

where \(f(x, y)\) is an input image, \(g_x\) is the result of the convolution between the input image and the sobel operator in the \(x\) direction, and \(g_y\) is the result of the convolution of \(f(x, y)\) with the sobel operator in the \(y\) direction.

The sobel operator consists of a pair of 3x3 kernels [Gonzalez, 2004].

\[
G_x = \begin{bmatrix}
1 & 0 & -1 \\
2 & 0 & -2 \\
1 & 0 & -1
\end{bmatrix}
\]  \quad (4.13)

\[
G_y = \begin{bmatrix}
1 & 2 & 1 \\
0 & 0 & 0 \\
-1 & -2 & -1
\end{bmatrix}
\]  \quad (4.14)

**Basic Intensity operations**

This operations are characterized by a histogram, \(h(g_k)\), of a digital image. Where \(g_k\) is the grey level of \(k\), \(h(g_k) = n_k\), and \(n_k\) is the number of pixels with grey level \(g_k\).

The histogram equalization assume for a moment that intensity levels are continuous quantities normalized to the range \([0,1]\). The occurrence of gray levels can also be provided in terms of probability values. The normalized histogram of a digital image is:

\[
p(g_k) = \frac{n_k}{n}
\]  \quad (4.15)

where \(n\) is total number of image pixels.

The histogram equalization can be considered as a discrete cumulative distribution function. In this function \(T\) is the mapping function:
This operation corresponding continuous operation gives rise to a uniform histogram.

The net result of this intensity level equalization process is an image with increased dynamic range, which will tend to have higher contrast. The values are approximations to the probability of occurrence of each intensity level in the image.

Other enhancement operation that results of a histogram modification is the histogram stretch. This operation is characterized by a gray-level scaling, when the higher and lower intensity, of the input image and of the histogram, is necessary to know. The histogram stretch results of:

\[
g = \frac{g_{\text{max}} - g_{\text{min}}}{f_{\text{max}} - f_{\text{min}}} (f - f_{\text{min}}) + g_{\text{min}}
\]  

(4.17)

where \( g_{\text{max}} \) is the maximum value of the histogram result, \( g_{\text{min}} \) corresponds to minimum value of the histogram, \( f_{\text{min}} \) and \( f_{\text{max}} \) are respectively the intensity values minimum and maximum [Gonzalez, 2004; Gonzalez, 2008].

Figure 4.6: Image shows a representation of the histogram stretch process (Image from Mendonça, 2010).
Non linear filters

In medical images, the noise signal can be observed as a higher frequency signal. So, a low pass filter can be used to remove or reduce noise [Qazi, 2008].

In general the frequency components can be expressed in low and high ranges. The high-frequency information belongs to sharp details, edges and noise, whereas low-frequency range components usually represent shapes and blurred structures in the image.

Frequency domain filtering methods process an image in the Fourier domain to emphasize or de-emphasize specific frequency components, but the convolution in the spatial domain is the same that the Fourier transform in the frequency domain. Therefore, can be obtained a low pass filter when is realized the convolution with the Gaussian kernel or mean kernel [Gonzalez, 2008; Qazi, 2008].
4.4.2 – Image Segmentation

The goal of segmentation is separation of structures of interest from background and each other based on one or more of several properties, such as texture, color, distribution of densities of the image elements, and motion field, etc. The result of segmentation is either an image with labeled regions or a set of contours describing the region’s boundaries. As for medical images, the purpose of segmentation is usually to extract known anatomic structures from images such as the vagina, the urethra, the bladder, the rectum, the levator ani muscle or to label abnormalities in tissues or organs such as tumors and cysts [Olabarriga, 2001].

Segmentation allows the quantitative measurements of structures and thus can assist doctors in confirming the existence of certain diseases and evaluating their severity.

In addition, segmentation results can be used to build an anatomical atlas, which is valuable for pre-surgical planning. Furthermore, dynamic or adaptive segmentation can track anatomical changes over time, making it very useful in image-guide surgery. The most general techniques of medical image segmentation are described in the following sections [Zhen Ma, 2009].

Segmentation Techniques

Model-free segmentation methods are based on local image properties such as intensity value, gradient magnitude, and textures. Image statistics tools such as histogram, mean, variance, and entropy can be used in this kind of segmentation. The following methods are the most frequently used model-free techniques [Zhen Ma, 2009].

Thresholding

Thresholding is one of the most widely used segmentation techniques for digital images. It separates the structures of interest based on signal intensity of these digital images. The thresholding operation can change the pixel values or categorize pixels into different groups based on one or more
specified values. There are two basic types of thresholding methods: binary thresholding and general thresholding. When the binary thresholding method is applied, a grayscale image can be transformed into a binary image by changing the pixels values according to the rules described in the Figure 4.7. If the intensive value of the pixel is less than the upper threshold and greater than the lower, the output of this pixel (inside value) is defined as 1 (white). Otherwise, the output (outside value) is defined as 0 (black) [Zhen Ma, 2009].

As for general thresholding, pixel intensities can be transformed with flexibility. One can define a threshold value, and any pixel with intensity value below or above this threshold will be replaced by a predefined value while all other pixels remain unchanged.

Alternatively, one can define a lower threshold value as well as an upper threshold value, and all pixels with intensity value within the threshold range will be replaced by a predefined value while all other pixels remain unchanged. The output of general thresholding is an image with a highlighted region of certain intensity, thus separating the structure of interest from the background.

There are some other thresholding techniques used in medical image segmentation including multi-thresholding and adaptive thresholding.
Through multi-thresholding, the number of significant intensity levels can be found and an optimum value between any two consecutive significant intensity levels can be selected to segment the images [Hannah Patel, 1995].

Adaptive thresholding is a technique to change the threshold dynamically over the image. With different threshold based on difference in the pixels, this method can deal with changing lighting conditions in the image, for example, those occurring due to a strong illumination gradient or shadows [Erdie, 1997].

The key to effective thresholding is to choose a proper threshold value. The thresholding segmentation method is simple and fast. However, it is sensitive to noise in low contrast images and usually generates isolated pixels instead of connected regions.

**Edge Detection**

Edge detection methods extracts discontinuities in the digital image and the results can be used for segmentation. It is because the pixels on the border of structure often have much higher or lower intensity values than those of neighboring pixels. Many operators can be used to extract edges, and most commonly used is the Canny operator in image segmentation since it can give continuous contour of objects [Ding, 2001]. Canny edge detection consists of four steps:

1) **Noise Reduction** – Edge detectors are susceptible to noise so Canny detectors smooth the raw image by using a filter based on the first derivative of a Gaussian.

2) **Edge Magnitude and Orientation Computation** – A structure’s edge may have a variety of directions, so the Canny algorithm uses four filters to detect horizontal, vertical, and diagonal edges and calculate the gradient magnitude.

3) **Directional Non-maximal Suppression** – In this step, a search is carried out to determine if gradient magnitude achieves a local maximum in the gradient direction.

4) **Hysteresis Edge Labeling** – There is one high thresholding value which is used for making the border or contour of high confidence and another low threshold value will be used to track faint sections.
Although, the Canny edge detectors is a powerful tool for 2D image segmentation, it cannot be directly applied to 3D volume images [Ding, 2001; Zhen Ma, 2009].

**Clustering**

Clustering means classifying objects into different groups according to certain properties, such as intensity, color, texture, and connectivity. Segmentation is used to determine to which data group a pixel or voxel naturally belongs. The most popular and simple technique is K-means clustering which usually consists of four steps:

1) K cluster centers are chosen randomly.

2) Each pixel in the image is assigned to the cluster to minimize the squared or absolute difference between the pixel and the cluster center.

3) The cluster centers are recalculated by averaging all of the pixels in the cluster.

4) Repeat the above step 2) and 3) until certain termination criteria are met.

The most common termination criterion is that there is no change in cluster membership compared to the previous iteration [Cinque, 2004]. Although convergence is guaranteed with this algorithm, the optimal solution may be not achieved. Some other clustering methods are developed based on the method of k-means. Some of them have achieved great improvement of image segmentation. These methods include fuzzy C-means, which gives the possibility of certain pixels belonging to each cluster. By setting the threshold value of the possibility, each cluster can contain greater or fewer pixels [Lin, 2008]. In addition, all clustering algorithms can easily be extended from 2D to 3D.

**Region Growing**

Region growing algorithms have lot of applications in medical image segmentation.

Region growing method has proved to be a very effective approach. The purpose of region growing is to produce spatially connected regions based on intensity homogeneity as well as geometrical proximity. A simple approach of region growing segmentation is to start with a seed region that
is confidently considered to be inside the target object. The pixels in the neighboring region are evaluated to determine if they belong to the object based on certain criteria. This process will continue and repeat until a certain stop condition is satisfied [Mehnert, 1997].

The performance of region growing segmentation is largely based on merging and termination criteria. The simplest merging criterion is to evaluate an intensity value to determine if it is inside a specific interval.

Another criterion for merging pixels is to minimize the error of misclassification.

The objective is to find a threshold that classifies the image into two clusters. Therefore, the area under the histogram for one cluster, locating on the other cluster's side of the threshold, can be minimized. The region growing method can easily be extended from 2D to 3D applications in medical image segmentation [Xinquan, 1998]. The advantage of region growing methods is their simplicity. The major disadvantage is that they are based on point wise comparisons, which can give jagged borders.

**Deformable Templates**

Deformable templates give a simple and compact representation of similar objects with variations in shape. Because the objects found in the family can be deformed to each other, an ideal template can be created. Depending on the intrinsic properties of the objects, a template can be created by a polygonal boundary model or triangulation model. The deformation of the template is constricted by defining the range of angle and ratio of length. When matching the template to a new image, the transformation parameters will be iteratively updated to change the template shape. By this means, the objective function is minimized and the best match between the deformed template and the edges in the image is achieved [Lipson, 1990]. The method can be effective in certain cases but it also complicated. The performance of the segmentation is mainly based on how a template is built; however, there is no general method to build templates or to choose the nodes for the polygonal boundary model.

Determining how to represent the shape by triangles is based on observation and experience [Zhen Ma, 2009].
Active Contours

Active contours, known as snakes, was a method first introduced in 1987 and has been used more and more frequently in medical image segmentation [Kass, 1987]. An active contour is a flexible spine, which detects specified properties of an image and can dynamically fit to the edges of an structure by minimizing an energy function. Initially, it is placed close to an object’s gradient [Kass, 1987]. The forces that control the curve or surface regularity are called “internal forces”. In order words, the curve or surface is given the physical properties of elasticity and rigidity, which guarantee that curve is always smooth while attracting to the boundary of objects. The active contour or surface method has limitations in the following areas:

1) The method depends on the initial positions of the contour or surface, which need to be carefully placed by the user.

2) The method depends on the quality of images. It is prone to give an error result when it is applied to a low contrast image: it either includes different structures in one contour, or misses a part of structure.

3) The method is complicated and requires a lot of computation during iterations.
4.5 – Summary

To achieve the enhancement is necessary eliminate high frequency noise while maintaining the sharp edges. The performed algorithms obtain results that only satisfy one of the parties.

The average filter and Gaussian filter perform smoothing behave as low pass filters. These filters soften the contours. When compared, it appears that the Gaussian filter has a better behavior because no blurs the edges too much.

The gradient operation should not be used without a performing a prior filtration.

The anisotropic diffusion filter blurs areas of low contrast and enhanced the high contrast (edges). This filter works as a high pass filter.

The histogram equalization and histogram stretch don’t present significant changes in the resulting images.

Thus, propose the use of a band-pass filter, which initially performs a Gaussian filtering and then an anisotropic diffusion filter. With this band pass filter the high frequency noise is eliminated and edges are enhanced.

Model free segmentation methods are based on local image features and properties. The advantage of these methods is that no training process is needed and one can quickly apply them to segment data. However, the disadvantage is that the segmentation is based on the quality of the image and can be easily misled by noise in the image. Thus, this method is mostly applied to high quality images, in which the target objects have high contrast and are easily identified. Although model-free methods are generally low-level segmentation methods, they could be used during the process of high-level segmentation pipeline, or as preprocessing filters.

An advantage of model-based segmentation methods is that the strong statistical background makes them very robust even if the quality of analyzed data is poor. The prior information about an object’s appearance helps to compensate for missing texture information. However, some disadvantages do exist: the training process is long, and optimization takes a lot of time and is not suitable for modeling objects which can only be identified in a special context or which do not have a fixed shape.

As conclusion, in segmentation of medical images, no one method is good for all applications but adequate segmentation could be obtained by using a variety of segmentation methods.
V – Final Considerations and Future Perspectives
5.1 – Final Considerations and Future Perspectives

The fact of the pelvic cavity has many physiological systems, therefore many organs, means that it can be affected by a multitude of diseases.

This reflects the clinical importance of this cavity and therefore there is the need for technological support and automatic, to facilitate the analysis and visualization of this region.

The processing and analysis of magnetic resonance images of the female pelvic cavity represent a key role in service delivery and technological development of equipment used in women's health.

The theoretical representation of techniques for processing and analysis facilitates the understanding and perception in relation to the following processing to be done, which is the application of methods to automate the identification of bodies.

After the segmentation and identification becomes clinically easy track the changes in the shape of organs, to perform the alignment of images (at once) and to construct 3D body to be observed.

The realization and optimization of this process is what I intend to accomplish in the future, as well as produce an interface capable of interacting with the operator.

The monograph served as a theoretical support to increase knowledge about the area of computer vision. The realization of this theoretical work has also enabled the growth of wisdom in the field of imaging, specifically magnetic resonance imaging.
References


