4.1 Medical imaging modalities and their applications

Medical imaging processes are applied through various stages of treatment: screening, diagnosis and evaluation and therapy. There are many types of imaging modalities but they are mainly classified into three categories:

- Invasive
- Minimally-invasive
- Non-invasive

Invasive imaging modalities require an incision for the introduction of the instrument for examination and assessment. On the contrary, non-invasive medical imaging techniques do not require breaking the skin or entering the body. Minimally invasive imaging modalities encompass smaller surgical incisions for shortening the healing time of the wound. Non-invasive imaging modalities are preferred over invasive and minimally invasive modalities because they are safe, risk-free, have no harmful radiation exposures and do not cause any damage to tissues of the human body [1].

Non-invasive medical imaging modalities are vast in number so for a better understanding of how these techniques work, we must get familiarized with a few terminologies related to them which are:

- Radiotracer and Radiopharmaceuticals: Radiotracer is a substance that has a radioactive molecule tightly bonded with another molecule. It can be administered through injection or can be swallowed. Radiotracers work on the principle of radioactive labeling. It is the process where an atom in the chemical compound is replaced by an isotope of the same element also called a radioisotope.

  A radiopharmaceutical is radiotracers that are approved by Food and Drug

Administration(FDA). Radiopharmaceuticals vary from modality to modality. For example, Technetium (99mTc) tilmanocept (tradename Lymphoseek) is used in SPECT scans and Tetrofosmin(Myoview) is used in PET scans [2].

- Artifacts: Artifacts refer to something that caught on an image but isn't present in reality. It is an error. They can be caused by resonant offsets, hardware limitations (radiofrequency non-uniformity) or motion (blood flow, respiration). An artifact is dependent on the type of imaging modality but some common artifacts include clothing artifacts(jewels) and patient-based artifacts (motion artifacts).
- Repetition time(TR): It refers to the period between consecutive pulse sequences applied to the same slice.
- Time to Echo(TR): It is the time duration between delivery of the RF pulse and arrival of the echo signal.

Different kinds of medical imaging modalities contain:

4.1.1 Invasive Imaging Modalities

(i) Intravascular Ultrasound(IVUS): Intravascular Ultrasound is an invasive imaging modality that is a combination of echocardiography and cardiac catheterization. Echocardiography uses high-frequency waves known as ultrasound to produce live images of the heart and cardiac catheterization is the insertion of a catheter into the chamber of the heart. The catheter is connected to a transducer which is guided through an artery and into the heart. The sound waves produced by the wall of the artery are captured by the transducer and these echoes are then converted into images. The application of IVUS includes identification of occult atherosclerosis in angiographically normal vessels, evaluating intermediate lesions, determining the extent of cardiac allograft vasculopathy and assessing the result of percutaneous transluminal coronary angioplasty [3,4].

4.1.2 Minimally Invasive Medical Imaging Modalities:

(i) Endoscopy: It is a procedure to look inside the body to examine any hollow cavity or organ. It is performed through an instrument endoscope. An endoscope is a long thin tubular instrument coupled with a tiny camera and powerful light source for illumination. There are many types of endoscopies as it is the procedure to review any part of the body. The following shows the region of interest and the types of endoscopies concerning them:

- For respiratory tract:
    i. Rhinoscopy: It is the procedure for examination of the nose using an instrument called a rhinoscope. It is divided into anterior and posterior rhinoscopy.
    ii. Laryngoscopy: It is the endoscopy of the larynx. This procedure can be done using direct or indirect laryngoscopy.
    iii. Bronchoscopy: The is the endoscopy concerning the lower respiratory tract predominantly areas like bronchioles, trachea, and lung.
- For ear canal:
    i. Otoscope: It is the endoscopy of the ear used to diagnose otitis media (an inflammatory disease in the middle ear region) and otitis externa (inflammation of ear canal).
- For urinary tract:

i. Cystoscopy: It is the endoscopy of the urinary tract and is used to diagnose conditions like hematuria, interstitial cystitis (also known as bladder pain syndrome) and other urinary tract infections.

- For female reproductive system:

  i. Colposcopy: It is the endoscopy of the cervix and is used to prevent cervical cancer by detecting precancerous lesions.

  ii. Hysteroscopy: It is the endoscopy of the uterus used for the diagnoses of Asherman's syndrome (intrauterine adhesions), adenomyosis, abnormal uterine bleeding(AUB) and removal of IUDs.

  iii. Falloposcopy: It is the endoscopy of fallopian tubes. It is used to assess and manage tubal infertility.

- For gastrointestinal tract:

  i. Esophagogastroduodenoscopy: It is the endoscpy of upper gastrointestinal tract (esophagus, stomach and duodenum) and used to evaluate dysphagia (difficulty in swallowing), odynophagia (painful swallowing), IBD (inflammatory bowel disease) and for the surveillance of ulcers and after a gastric surgery.

  ii. Enteroscopy: It is the endoscopy of the small intestine. It is used to diagnose gastrointestinal bleeding and other related conditions.

  iii. Colonoscopy: It is the endoscopy of the large intestine and is used to diagnose ulcers, gastrointestinal hemorrhage and detection of colorectal cancers.

- Proctoscopy: For the endoscopy of both rectum and anus and is used for the screening of colon cancer and diagnosis of the conditions such as bleeding, hemorrhoids.
- During pregnancy:
    i. Fetoscopy: The procedure that allows surgical access to the fetus. The endoscope is entered through a small incision and is placed into the amniotic sac through the uterus.

The risk related to endoscopy are infections, tear of the stomach lining or the lining of the esophagus, over-sedation and bleeding. In case of perforation, surgery is required but otherwise, most causes can be treated with antibiotics and intravenous fluids. Minor bleeding may simply stop by itself or can be stopped by cauterization.

(ii) Virtopsy: Virtopsy as the term suggests is a portmanteau of words virtual and autopsy. The traditional way of postmortem is an invasive body-opening autopsy to which the best current alternative is virtopsy.

To conduct a virtopsy the following photographic and medical tools are required:

- 3-D optical surface scanner
- CT scanner for postmortem CT (PMCT)
- MRI scanner for postmortem MRI(pm-MRI)

The virtopsy is performed as follows:

- A 3D surface scan is used to create a 3D color model of the body.
- The body is placed in a sealed bag and put through a CT scan. The sealed bags prevent contamination of the body from x-rays.
- The CT scan is used to render images of the body for examination.

- The scanned images provide clear and detailed information on bullet paths, internal bleeding and hidden fractures which are hard to find in traditional autopsy [5,6].

The virtopsy method offers the following advantages:

- Preservation of body in virtual form.
- It is fast, detailed and almost accurate to a traditional autopsy.
- It provides information on difficult to access areas of the body (e.g. atlanto-occipital joints).
- It maintains the religious belief of the community about bodily integrity.

The main disadvantage of virtopsy is that it has a high equipment cost and is relatively a new field of study.

4.1.3 Non-Invasive

(i) Radiography: Radiographic examinations are essential in the field of medicine to provide both physicians and surgeons with static and moving images of body structures for diagnosis and treatment planning. This medical imaging modality uses X-rays, gamma rays or similar ionizing radiation and non-ionizing radiation for viewing the internal form of an organ. The images produced via this technique are also called roentgenograms or X-rays. Radiography is used for both diagnostic and therapeutic purposes in medicine. Medical ailments such as breast cancer, osteoporosis, pneumonia, kidney and bladder stones, arthritis, blood clots, peripheral artery disease (PAD), lung cancer, breast cancer, colorectal cancer can be detected and screened using radiography. The merits and demerits of radiography include:

- Merits:

    i. It is a cheaper and simple technique.

    ii. It has lower radiation compared to a CT scan.

    iii. It can eliminate the requirement for surgery.

- Demerits:

    i. The image thus processed is available in a 2D format and hence less informative to a 3D image produced by other means.

    ii. It has limited abilities to detect finer cracks and is sensitive to defect orientation.

Radiography finds its uses in orthopedics, pulmonology, dentistry and oncology.

(ii) Computed Tomography scan (CT scan): CT scan or CAT scan is a medical imaging technique that uses an X-ray scanner to take cross-sectional images of the body. It uses energy beams to generate multiple detailed images of various organs and structures within the body, including bone, muscles, fat and water. It produces 3D interactive reconstructions which are precise and give an idea of how organs function together as part of larger systems such as muscles or blood vessels. There are three major types of CT scans:

- Spiral CT: Spiral CT or helical CT scans the entire X-ray tube is spun around the central axis of the area being scanned. It produces detailed scans that may be better at finding small abnormal areas inside the body. These are the dominant type of scanners used in the medical industry because they offer a lower cost of production and purchase.

- Electron beam tomography: Electron beam tomography(EBT) is a type of computed tomography where an electron gun is used to scan for abnormalities. The advantage of EBT machines is that the X-ray source-point is swept electronically, not mechanically, it can be swept with far greater speed. This enhances the quality of the scan obtained and improves the accuracy of the scan. EBT is specifically used for imaging of moving structures, such as the heart and arteries (coronary angiogram).
- CT perfusion imaging: Computed tomography (CT) perfusion imaging is the imaging technique that shows which areas of the brain are adequately supplied or perfused with blood and provides detailed information on the blood flow to the brain. It is better for stroke diagnosis than other CT types.

(iii) Magnetic Resonance Imaging(MRI): Magnetic Resonance Imaging(MRI) or Nuclear Magnetic Resonance Imaging (NMRI) generates diagnostic images without the use of X-rays or ionizing radiation, which distinguishes it from Radiography and CT scans. It is the medical application of nuclear magnetic resonance(NMR). MRI is widely used because of its non-ionizing nature. The images are created by varying the sequence of radiofrequency(RF) pulse and the image contrast is dependent on two tissue-specific parameters:

- The longitudinal relaxation time(T1): It is the time constant that determines at the rate which energized protons return to equilibrium.
- The transverse relaxation time(T2): It is the time constant that determines the rate at which energized protons reach equilibrium.

By reconfiguring repetition time (TR) and time of echo(TE) MRI images are made to contrast different tissue types:

- T1 weighted MRI: These images are produced by using short TR and TE times and has the following characteristics:
    i. Fat and meniscal tear appear white.
    ii. Water, CSF, muscle, tendons, ligaments appear light to dark gray.
    iii. Air and conical bones appear dark.
- T2 weighted MRI: These images are produced by using longer TR and TE times and have the following characteristics:
    i. Water and CSF appear bright white.
    ii. Fat, muscle, tendons ligament appears light to dark gray.
    iii. Air and conical bones appear dark.

Some prominent medical applications include:

- Neuroimaging: Neuroimaging or brain imaging is a non-invasive technique to construct an image of the nervous system to study its structure and functions. It specifically deals with conditions like dementia, cerebrovascular disease, infectious diseases, Alzheimer's disease and epilepsy.
- Cardiovascular magnetic resonance imaging(CMR): CMR is the non-invasive imaging technique for the evaluation of the structure and function of the heart. It is specifically used for the assessment of conditions like myocardial ischemia and viability, cardiomyopathies, myocarditis, iron overload, vascular diseases and congenital heart disease. [2]

- Magnetic resonance angiography(MRA): MRA is the imaging technique used to image arteries. It is used for evaluation of stenosis (abnormal narrowing of blood vessels), occlusions (closing of blood vessels), aneurysms (vessel wall dilatations), congenital abnormalities in blood vessels (malformations in the heart due to congenital heart disease) and other abnormalities.

Even though MRI does not use ionizing radiation, there are still dangers related to it. It is advised that patients or individuals with steel implants or synthetic joints as the strong magnetic field used by the scanner may dislodge or heat them. [7]

(iv) Ultrasound: Ultrasound is one of the most risk-free and cost-effective methods of medical imaging. It uses sound waves to produce images of the inside of the body. This technique uses a high-frequency transducer that sends sound waves traveling through the body. Once the waves get deflected to the transducer, they produce the image for prognosis. Ultrasound is a cost-effective and a mobile option of medical imaging, but it also has its demerits which include:

- It generates a low-quality image that needs skilled interpretation.
- It may be incapable of indicating whether a mass is malignant or not.

Since ultrasound is a non-ionizing type of medical imaging modality, it is considered pregnancy-friendly and is the best choice in case of pregnancies. It is mainly used in cardiology, gynecology and obstetrics, urology and gastrology. [8,9,10]

(v) Single-Photon Emission Computed Tomography(SPECT): Single-Photon Emission Computed Tomography scan is an imaging technique that uses gamma rays to render a 3-D image of the scanned section/area generated from a large number of projection images captured from multiple angles. This technique incorporates the use of radiopharmaceuticals injected into to patient's body which is then detected by the collimated radiation detectors. The data acquired is then reconstructed into a 3-D format for interpretation [11]. Some widely used radiopharmaceuticals include:

- Technetium (99mTc) exametazime or Ceretec
- Technetium (99mTc) sestamibi or Cardiolite
- Technetium-99m-teboroxime or CardioTec
- Iobenguane i-131 or MIBG [2]

The most common use of SPECT is for tumor imaging, infection imaging, and bone scan or bone scintigraphy. Specific examples include:

- Functional Brain Imaging: It uses radiopharmaceuticals like Technetium (99mTc) exametazime which detects the gamma rays emitted from the patient's body and produces an image of the malignant area or region for diagnosis. It is used to diagnose dementia, Alzheimer's disease, epilepsy, brain seizures and so on.
- Bone Scintigraphy: Bone Scintigraphy is the tomographic procedure that allows rendering an image of a scanned area/region, mainly for the diagnosis of bone-related issues. It is used to diagnose conditions such as arthritis (joint inflammation), benign bone tumors, Paget's disease (thickening and softening of the bones and curving of the long bones), avascular necrosis (death of bone tissue due to lack of blood supply to the bones).
- Myocardial Perfusion Imaging (MPI): Myocardial perfusion imaging is a medical imaging technique that involves scanning the condition of the heart muscle(myocardium) before and after a stress test. The stress test shows the

physical stress on the blood flow through the coronary arteries and the heart muscle. It is used mainly for the diagnosis of heart diseases such as coronary artery disease(CAD) and for the detection of myocardial infarction (blockage of blood flow to the heart).

(vi) Positron Emission Tomography(PET): While imaging modalities such as computed tomography(CT) and magnetic resonance imaging(MRI) capture the size and shape of the tumor, positron emission tomography is based on the metabolism of the body tissue. PET scan works on the fact that cancer cells metabolize sugar(glucose) more rapidly than normal cells. The image produced thus has functional as well as biochemical changes and indicates the metabolic changes occurred which with skillful interpretation and biochemical analysis is diagnosed. Since PET is a type of nuclear medicine, a certain amount of radiopharmaceuticals such as Sodium Fluoride, Rubidium Chloride, Fludeoxyglucose are used for assisting in evaluation. The principle behind PET scans is that the radiopharmaceutical which is administered intravenously to the patient emits radiation which is detected by the detectors positioned around the patients. The image is produced from the projection data collected by the PET's system computer. This projection data is then reconstructed into a 3-D image of the region scanned.

Since PET is an emerging field in medical imaging, overtaking SPECT scanners, PET scans are mainly used for the diagnosis of conditions in the field of oncology, neurology and cardiology. [12,13]

The advantages of PET scan include:

- It provides a detailed medical image with good resolution and high sensitivity.

- It produces fewer artifacts than SPECT scans. Artifacts are features that appear in the scan but are not present in the original object.
- It generates less attenuation than SPECT scans. Attenuation is the process of removal of soft tissue artifacts from medical images. [14]

PET scans provide better results both in terms of image quality and detail but they also cost more. For comparison, a SPECT scanner costs around $400,000 to $600,000 while a PET scanner costs around $2M. Also, the radiotracers or radiopharmaceutical production for PET scans cost a lot more than its production for SPECT.

(vii) Functional Near-Infrared Spectroscopy (fNIRS): Functional Near-Infrared Spectroscopy is an emerging field in neuroimaging, providing a more detailed and accurate analysis of the outer cortex of the brain [15,16]. It relies on the hemodynamic response, which is also known as the Blood-Oxygen-Level-Dependent (BOLD) response that evaluates the changes in deoxygenated and oxygenated hemoglobin concentrations of the cortex. fNIRS is a medical imaging modality that is complementary to other imaging techniques like functional magnetic resonance imaging(fMRI) and electroencephalogram (EEG) [17]. fMRIs are based on the assessment of the changes in blood flow of the brain. EEG is a medical test based on the evaluation of the electrical activity of the brain. [18] The advantages of fNIRS are:

- It is relatively inexpensive, portable and easily accessible.
- It has a high temporal resolution. Temporal resolution refers to the time required for the retrieval of a single frame in a dynamic image. fNIRS provides a temporal resolution of 0.01 seconds.

- It also is immune to motion artifacts and invulnerable to the electromagnetic environment.
- It is non-invasive and non-ionizing (concerning fMRI).
- It is highly compatible with other neuroimaging modalities. [14,19]

fNIRS has a wide range of applications such as cerebral oximetry, diffuse optical tomography, hyperscanning.

Photoacoustic Imaging: Photoacoustic imaging is a bioimaging modality that works on the photoacoustic effect. The formation of a soundwave by absorption of light by a material is called the photoacoustic effect. The soundwaves(Ultrasound) are picked up by a detector and rendered as images. It is a hybrid modality combining optical imaging with ultrasound detection.

(viii) Photoacoustic imaging differs from other modalities because it renders an image based on the contrast of optical absorption of the tissue rather than their mechanical and elastic property. It has the following merits over other imaging modalities:

- It uses non-ionizing radiation and has near real-time imaging capabilities.
- It offers high-resolution multispectral images with high penetration depth.
- It offers minimal acoustic noise.
- It has a low cost of operation and it is a mobile unit.

Its limitations include:

- It is not applicable for cellular imaging.
- It shows weak absorption at short wavelengths.
- It is temperature-dependent.

4.2 Machine leaning and image processing

Machine learning algorithms have a specific pipeline or series of steps to learn from data.

Firstly, machine learning algorithms need a considerable amount of high-quality data to learn from and predict highly accurate results. Hence, we have to make sure that the images are properly processed, annotated, and are generic for machine learning image processing. This is where Computer Vision comes into the picture; it's a field concerning machines being able to understand the image data. Using computer vision, we can process, load, transform and manipulate images to build an ideal dataset for the machine learning algorithm.

For example, let's say we want to build an algorithm that will predict if a given image has a dog or a cat. The data we collect or produce is mainly undeveloped data, which means it shouldn't be used directly in applications for many possible reasons. Therefore, we need to analyze it first, do the necessary preprocessing using computer vision, and then apply it. The preprocessing steps include:

- Converting all the images into the same format and remeasuring them into standard size.
- Cropping out the unnecessary regions on images.
- Converting them into numbers for algorithms to learn from them(array of numbers).

Each image is represented by an array of pixels i.e. a matrix of pixel values. In the gray image, the pixel values range from 0 to 255 which represents the intensity of that pixel. For example, if you have a 20 x 20 sized image, it will be represented by a 20×20 matrix (total value of 400 pixels). While working with a colored image, there will be three channels – Red, Green, and Blue (RGB). Therefore, there will be three such matrices for one image.

The data that is processed is then used in the next phase: to choose and to build a machine-learning algorithm to categorize unknown feature vectors given an extensive database of feature vectors whose classifications are known. To do this, we need to choose an ideal algorithm.

The algorithms learn from the patterns based on the training data with specific parameters. However, one can always fine-tune the trained model based on its performance metrics. In conclusion, we can use the trained model to make new predictions on unseen data. [32]

Deep learning and image processing

Deep learning uses neural networks to learn effective presentations of features directly from data. For example, you can use a pretrained neural network to recognize and get rid of noises from the images.

Natural images are a collection of various objects with different structures. This

allows the neural network to learn complex and different filters especially in the deeper layers.

As discussed previously, Supervised Learning is an approach to learning, that requires a known dataset. This dataset is provided with

both inputs and correct outputs for the algorithm used.

Utilizing dataset as example the algorithm is guided to define a model which is able to predict the correct output. At this point, the predictions must be validated with another known dataset independent from the training set. Only when the validation phase is convincing, the algorithm can be considered as reliable and used for unknown data.

1.**Algorithm selection**: The first step is to choose the algorithm to be used. The choice of algorithm will depend on the problem and the kind and amount of data available. Some of these algorithms which can be used are: Support Vector Machine (SVM), Decision Tree, Artificial Neural Network and Deep Learning.

2.**Training**: This is the most important phase as the final performances depend on the predictive model built.

A known dataset is selected which represents the problem at stake. Using a dataset which isn’t general enough can lead to over fitting and hence bad performance. This training dataset must provide an output(label) for each input listed.

The algorithm is trained with the selected dataset. The aim is to build a model that will make accurate predictions for each input.

3.**Validation**: In this phase the performance achieved by the prediction model built is tested. Another known dataset, called as the test dataset is prepared. This dataset must provide accurate input and output

for each example and should be as independent as possible from the training dataset. The model built in the previous phase is used to predict the output data ofthe test set by using the input. Using only the input, the output is predicted by the algorithm and stored. The difference between training and validation is that, in validation, the output label is not used to improve the accuracy of prediction of the model, but only to evaluate its performances. The predicted outputs are validated using.[33]

What is image recognition?

Image recognition, a subcategory of Computer Vision and AI , represents a group of methods for detecting and analyzing images to enable the automation of a selected task. It is a technology that's capable of identifying places, people, objects and lots of other sorts of elements within a picture , and drawing conclusions from them by analyzing them.

If you are interested in this topic, see our article explaining the difference between image recognition and computer vision.

Photo or video recognition can be performed at different degrees of accuracy, depending on the type of information or concept required. Indeed, a model or algorithm is capable of detecting a specific element, just as it can simply assign an image to a large category.

So there are different “tasks” that image recognition can perform:

- **Classification**. It is the identification of the “class”, i.e. the category to which an image belongs. An image can have just one class.
- **Tagging.** It is also a classification task but with a better degree of accuracy. It can recognize the presence of several concepts or objects within a picture . One or more tags can therefore be assigned to a specific image.
- **Detection**. This is necessary once you want to locate an object in a picture . Once the thing is found , a bounding box is placed round the object in question.
- **Segmentation**. This is also a detection task. Segmentation can locate a component on a picture to the closest pixel. For some cases, it's necessary to be extremely precise, as for the event of autonomous cars.[24]

Convolutional Neural Networks (CNN)

Convolutional Neural Networks (CNN) is one of the variants of neural networks used heavily in the field of Computer Vision. It derives its name from the type of hidden layers it consists of. The hidden layers of a CNN typically consist of convolutional layers, pooling layers, fully connected layers, and normalization layers. Here it simply means that instead of using the normal activation functions defined above, convolution and pooling functions are used as activation functions.

Recurrent Neural Networks (RNN)

Recurrent Neural Networks or RNN as they are called in short, are a very important variant of neural networks heavily used in Natural Language Processing. In a general neural network, an input is processed through a number of layers and an output is produced, with an assumption that two successive inputs are independent of each other.

This assumption is however not true in a number of real-life scenarios. For instance, if one wants to predict the price of a stock at a given time or wants to predict the next word in a sequence it is imperative that dependence on previous observations is considered.

Image Enhancement :-

We introduce the concept of image filtering based on localized image subregions (pixel neighborhoods), outline a range of noise removal filters and explain how filtering can achieve edge detection and edge sharpening effects for image enhancement.

Why perform enhancement?

The basic goal of image enhancement is to process the image in order that we will view and assess the visual information it contains with greater clarity. Image enhancement, therefore, is quite subjective because it depends strongly on the precise information the user is hoping to extract from the image. The primary condition for image enhancement is that the knowledge that you simply want to extract, emphasize or restore must exist within the image. Fundamentally, ‘you cannot make something out of nothing’ and therefore the desired information must not be totally swamped by noise within the image. Perhaps the foremost accurate and general statement we will make about the goal of image enhancement is just that the processed image should be more suitable than the first one for the required task or purpose. This makes the evaluation of image enhancement, by its nature, rather subjective and, hence, it's difficult to quantify its performance aside from its specific domain of application.[22]

Image segmentation

Segmentation is the name given to the generic process by which an image is subdivided into its constituent regions or objects. In general, completely autonomous segmentation is one among the foremost difficult tasks within the design of computer vision systems and remains a lively field of image processing and machine vision research. Segmentation occupies a really important role in image processing because it's so often the vital initiative which must be successfully taken before subsequent tasks like feature extraction, classification, description, etc. can be sensibly attempted. After all, if you can't identify the objects within the first place, how are you able to classify or describe them? The basic goal of segmentation, then, is to partition the image into mutually exclusive regions to which we will subsequently attach meaningful labels. The segmented objects are often termed the foreground and therefore the remainder of the image is that the background.

Note that, for any given image, we cannot generally speak of one , 'correct' segmentation. Rather, the correct segmentation of the image depends strongly on the types of object or region we are interested in identifying. What relationship must a given pixel have with reference to its neighbours and other pixels within the image so as that it's assigned to at least one region or another? This really is that the central question in image segmentation and is typically approached through one among two basic routes:

- Edge/boundary methods This approach is predicated on the detection of edges as a way to identifying the boundary between regions. As such, it's for sharp differences between groups of pixels
- Region-based methods This approach assigns pixels to a given region supported their degree of mutual similarity.

Region growing and region splitting

Region growing is an approach to segmentation during which pixels are grouped into larger regions supported their similarity consistent with predefined similarity criteria. It should be apparent that specifying similarity criteria alone isn't an efficient basis for segmentation and it's necessary to think about the adjacency spatial relationships between pixels. In region growing, we typically start from variety of seed pixels randomly distributed over the image and append pixels within the neighbourhood to an equivalent region if they satisfy similarity criteria concerning their intensity, colour or related statistical properties of their own neighbourhood. Simple samples of similarity criteria might be:

- absolutely the intensity difference between a candidate pixel and therefore the seed pixel must lie within a specified range;
- absolutely the intensity difference between a candidate pixel and therefore the running average intensity of the growing region must lie within a specified range;
- the difference between the standard deviation in intensity over a specified local neighbourhood of the candidate pixel and that over a local neighbourhood of the candidate pixel must (or must not) exceed a certain threshold – this is a basic roughness/smoothness criterion.

Many other criteria can be specified according to the nature of the problem. Region splitting essentially employs an identical philosophy, but is that the reverse approach to region growing. In this case we start the segmentation procedure by treating the entire image as one region which is then successively weakened into smaller and smaller regions until any further subdivision would result in the differences between adjacent regions falling below some chosen threshold. [22]

Tensorflow

TensorFlow may be a machine learning system that operates at large scale and in heterogeneous environments. TensorFlow uses dataflow graphs to represent computation, shared state, and therefore the operations that mutate that state. It maps the nodes of a dataflow graph across many machines during a cluster, and within a machine across multiple computational devices, including multicore CPUs, generalpurpose GPUs, and custom-designed ASICs known as Tensor Processing Units (TPUs). This architecture gives flexibility to the appliance developer: whereas in previous “parameter server” designs the management of shared state is made into the system, TensorFlow enables developers to experiment with novel optimizations and training algorithms. TensorFlow supports a variety of applications, with a focus on training and inference on deep neural networks. Several Google services use TensorFlow in production, we've released it as an open-source project, and it's become widely used for machine learning research. we describe the TensorFlow dataflow model and demonstrate the compelling performance that TensorFlow achieves for several real-world applications.[26]

Pytorch

Deep learning frameworks have often focused on either usability or speed, but not both. PyTorch may be a machine learning library that shows that these two goals are actually compatible: it provides an important and Pythonic programming style that supports code as a model, makes debugging easy and is consistent with other popular scientific computing libraries, while remaining efficient and supporting hardware accelerators such as GPUs.we detail the principles that drove the implementation of PyTorch and how they are reflected in its architecture. We emphasize that each aspect of PyTorch may be a regular Python program under the complete control of its user. We also explain how the careful and pragmatic implementation of the key components of its runtime enables them to figure together to realize compelling performance. We demonstrate the efficiency of individual subsystems, as well as the overall speed of PyTorch on several common benchmarks.

With the increased interest in deep learning in recent years, there has been an explosion of machine learning tools. Many popular frameworks like Caffe , CNTK , TensorFlow, and Theano, construct a static dataflow graph that represents the computation and which may then be applied repeatedly to batches of data. This approach provides visibility into the entire computation before time, and may theoretically be leveraged to enhance performance and scalability.

However, it comes at thevalue of simple use, simple debugging, and adaptability of the kinds of computation which will be represented. Prior work has recognized the worth of dynamic eager execution for deep learning, and a few recent frameworks implement this define-by-run approach, but do so either at the value of performance or employing a less expressive, faster language (Torch, DyNet), which limits their applicability. However, with careful implementation and style choices, dynamic eager execution are often achieved largely without sacrificing performance. This paper introduces PyTorch, a Python library that performs immediate execution of dynamic tensor computations with automatic differentiation and GPU acceleration, and does so while maintaining performance like the fastest current libraries for deep learning. This combination has clothed to be very fashionable within the research community with, as an example , 296 ICLR 2019 submissions mentioning PyTorch.[27]

Webgazer

We introduce WebGazer, a web eye tracker that uses common webcams already present in laptops and mobile devices to infer the eye-gaze locations of web visitors on a page in real time. The eye tracking model self-calibrates by watching web visitors interact with the online page and trains a mapping between features of the attention and positions on the screen. This approach aims to supply a natural experience to everyday users that's not restricted to laboratories and highly controlled user studies. WebGazer has two key components: a pupil detector which will be combined with any eye detection library, and a gaze estimator using multivariate analysis informed by user interactions. We perform an outsized remote online study and a little in-person study to guage WebGazer. The findings show that WebGazer can learn from user interactions which its accuracy is sufficient for approximating the user’s gaze. we release the primary eye tracking library which will be easily integrated in any website for real-time gaze interactions, usability studies, or web research.[28]

4.3 Future scope and recent developments in the field of medical imaging

Till now we have seen what are the different medical imaging modalities, their diagnosis, how they work and the different frameworks and libraries used to build such modalities. In this section, we shall focus on the recent developments in this field and its future scope.

Medical imaging saves millions of lives every year. Over the last 25 years, this industry has revolutionized the health care sector itself. It has gone from the usage of analog to digital devices; invasive to non-invasive techniques, and from a pixelated 2D representation to a colored 3D representation greatly enhance imaging capabilities and performance thus aiding the detection and diagnosis of conditions and disease. Due to the vital research and technological revolution, there have been numerous advances in the field of medical imaging.

(i) Hybrid modalities: We are familiarized with different types of medical imaging modalities such as MRI, PET, CT, SPECT which play a crucial role in diagnosis and other applications. Hybrid modalities or multimodality imaging is the combination of two or more individual modalities for better assessment and diagnosis. The purpose behind these hybrid modalities is that they should save time and provide more conclusive results than individual modalities. Modalities like SPECT/CT, PET/CT, PET/MR are a few examples of hybrid modalities.

- SPECT/CT: This hybrid modality is designed to have a camera that includes one SPECT scanner and one CT scanner so that the image generated has detailed information from both scans (coregistered image). It has the following merits:

    i. It provides clarity where other diagnostic modalities turn out to be inconclusive.

ii. Its detection capabilities are better than other modalities.

iii. It is time-saving. SPECT/CT has a minimum time duration of 30-45 minutes.

This hybrid modality is showing huge developments due to recent advancements in technologies. Some of them are:

i. Theranostics: It is a new approach in which diagnosis and therapy is combined to achieve a personalized treatment for the specific patient. In relation to SPECT/CT, it coordinates nuclear medicine with standard radiation oncology setting a model for personalized molecular oncology and precision medicine.

ii. Minimizing radiation: A common trend moving forward in radiology as to reduce radiation exposure to patients.

iii. Full body SPECT/CT: Unlike planar scans, a whole-body scan provides more detailed and structured features. it has better capabilities for the detection of bone metastasis and other conditions.

- PET/CT: Just like SPECT/CT, PET/CT is a hybrid modality that has a camera that combines a PET scanner and a CT scanner to generate an image that the combination of the two scans (coregistered image). It revolutionized the medical diagnosis by rendering images that show acute anatomical localization which was not a part of pure PET imaging. PET/CT differs from SPECT/CT in its functionality and also the radiotracer or radiopharmaceutical used. SPECT employs a single photon emitter while PET uses a positron emitter that produces two photons in opposite directions.

- PET/MR: Positron emission tomography-magnetic resonance imaging is multimodality that renders an image based on characteristics of PET (morphological imaging) and MRI (functional imaging). It is regarded as a better choice than PET/CT because MRI renders images based on tissue contrast (T1 and T2 weighted MRIs) which provide better features than an image taken by PET/CT. Other advantages include:
    i. It offers more accurate diagnostic capabilities (about 50% more) than PET/CT.
    ii. It offers less radiation exposure than PET/CT as MRI offers non-ionizing radiation.
    iii. It offers improved soft-tissue contrast over PET/CT [10].

  The major drawback of PET/MRIs is their cost and numbers as they are greatly expensive over PET/CT machines and very few.

(ii) Virtual reality and 3D imaging: Virtual reality(VR) has more uses than just video game industries and other recreational purposes. Currently, our scanners and modalities can produce more than two-dimensional images; they are capable of producing various vibrant and informative scans using multimodalities. In upcoming decades, we aim to shift to virtually three-dimensional rendered scans which may show all the intricate and necessary information that cannot be seen in two-dimensional images or reconstructed 3D images. The power of virtual reality coupled with 3D printing can be used to enhance the accuracy of the diagnosis and limit guesswork. 3D printing can be used to print the region of interest and this can be used for diagnosis and even educational purposes.

(iii) Artificial intelligence: AI is not just a branch of technology that impacts the future of medical imaging rather its main strength lies in the unification of different sectors of technology thus revolutionizing all these sectors. With essential research and investment, AI can transform the healthcare industry. Major trends include:

- Brain-computer interfaces.
- Innovation of next-generation imaging and radiological tools.
- Accessibility and expansion to remote areas.
- Aiding in the improvement of accuracy and analytics for pathology.
- Development of Smart Machines.
- Monitoring health via compact and small wearables.
- Transforming smartphones into diagnostic tools.
- Shifting from EHR (electronic health record) to more AI-maintained and automated processes.
- Identification of ailment patterns and incorporating personalized diagnostics.

There have recent advancements in AI-based technology. Few examples include:

- Google's DeepMind: It can assess 50 distinguished ophthalmic conditions with near 100% accuracy.
- ProFound AI: It is developed by iCAD and is used in the diagnosis of breast cancer.
- Siemens Healthineers & Intel teamed up to explore the improvements that can revolutionize cardiac MRI diagnostics.

The urgent need for human-aware AI systems and the need to transform the healthcare industry will exponentially expand the AI healthcare market and ensure its future development and delivery of promising services. According to Data Bridge Market Research, global artificial intelligence in the healthcare market is expected to reach 123.14 Billion USD by 2028.

(iv) Intraoperative imaging: Intraoperative means a procedure that happens during the duration of surgery. Thus, we explain intraoperative imaging as imaging techniques that are performed (and aid) during surgery so that it is a clean and precise operation. The evolution of imaging modalities has made it an important commodity and in this scenario, it is used for verifying surgical accuracy. It is used in all surgeries ranging from neurology to spine surgeries. Fluoroscopy, Cone Beam CT, Fan Beam CT are a few examples of intraoperative imaging.

(v) Wearable technology: Wearables have become a lot popular in the last decade. They can be distinguished into two main categories:

- General-purpose wearables
- Medical-specific wearables

General-purpose wearables include devices that are used for collecting general medical information such as heart rate, steps counter and calories burned. This is more of a feature provided rather than a full medical-based application. The device and application used are:

Devices:

- Fitbit
- Mi Smart Band
- Apple Watch

- Garmin

Apps:

- StepSetGo
- Google Fit

Medical-specific wearables are designed to monitor and assess a particular condition or ailment. In patients, these devices are used to monitor vitals and report in case of any disturbance. Few notable wearables include:

- MEG Brain Scanner: Magnetoencephalography(MEG) portable brain scanner manufactured by companies RICOH-USA helps providing a precise mapping of brain activity and monitor the electromagnetic activity of the brain. The scanner detects absolute neuron activity and thus holds an edge over fMRI and EEG.
- MRI Glove: This device provides clear and consistent images of moving tendons and joints hence giving insight into the anatomy of the hand.

(vi) Big data in healthcare and imaging informatics: Big data is a systematic method to analyze data sets that are too large, diverse and complex. In the healthcare sector, the recent method of data set collection is by:

- Electronic health records(EHR)
- Medical Imaging
- Pharmaceutical research
- Wearables
- Medical devices [11].
- Health examinations
- Genetic databases

Big data helps to dismantle and explore data sets generated by such methods to uncover hidden insights that improve patient care. Some renowned Big Data platforms include Hadoop and NoSQL.

Imaging informatics provides efficient, accurate and trustworthy medical imaging services. We know of computed aided diagnostic imaging techniques and imaging informatics helps in evolving it to computer-only diagnosis.

(vii) Augmented Intelligence and Reality: Augmented intelligence is similar to artificial intelligence. AI is real-time emulation of human behavior whereas augmented intelligence allows human inputs and interaction with the augmented environment. Even though this is a relatively new research area major advancements have been made [13]. Its application includes:

- AR as a medical education platform: It provides an interactive and user-friendly environment of learning and education. AR can create models of the structure understudying and they can also be printed via a 3D printer. The particular applications include training nurses and ARnatomy.
- Preparations of crowns and caps in dentistry.
- Location of vein on patients using AccuVein.
- Projection of anatomical parts by 3D holography introduced by SentiAR
- Improvements in aids for visually impaired (VA-ST's SmartSpecs)
- Evolving remote surgery: It is an act of performing surgery, even though the surgeon and the patient aren't at the same location. The AR simulates the whole process with the help of an expert who leads it and is performed in real-time by other fellow surgeons.

Advances in app development have provided great accessibility to AR apps from PlayStore(Andriod) and Apple Store. Few examples include:

- EyeDecide: It allows the visualization and learning of anatomical features of the eye and educate us about the various eye defects such as cataract and muscular degeneration.
- DoctorMole: It is used for the analysis of melanoma which in rare cases happen due to the growth of mole.
- Medic AR: It is based on the Google Glass app for surgeons that aids in the alignment of incision points.
- MEVIS surgery app: A real-time 3D image rendering app.
- Anatomy 4D: An educational app.

The Road Ahead

Medical imaging in the healthcare sector is evolving at a great pace but to ensure innovations and changing ideas into reality pose a greater challenge. Moving on, we need to focus on the cost-effectiveness and accessibility of such modalities and innovation of new hybrid modalities, transforming computer-aided techniques to solely computer performed techniques, developments in fully integrated medical systems and inter-system communication, improving and enhancing the role of AR and VR, automating the workstream and much more. When we can achieve all or even a part of the above-mentioned ideas and successfully implement it (or them), it would tremendously boost the development of the healthcare sector taking us closer to a future of endless possibilities.