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# Introduction to Digital Image Processing

Vision is one of our advanced senses that allow us to understand the environment around us. This vision enables us to perceive the environment visually using images. However, our vision is very limited and we can see through a narrow band in electromagnetic spectrum. Hence, we need other devices that can better visualize, can see beyond the human eye capability and can dive deeper in information obtained. The area of digital image processing lies under the larger domain of computer science known as **Artificial Intelligence (AI)** that tries to emulate human like intelligence. There are multiple application areas where digital image processing is required which can be categorized under two broad categories. 1) improving and enhancing the quality of images for visual perception and interpretation 2) processing of image data for storage, transmission and information extraction.

## 1.1 The digital image processing

An image is a 2D function  $f(x, y)$  that maps light intensity values to pixel locations. We start our discussion with gray scale images where the different shades of gray are used to represent the image. Figure 1-1: A) Grayscale and B) Grayscale Image shows a gray scale image.

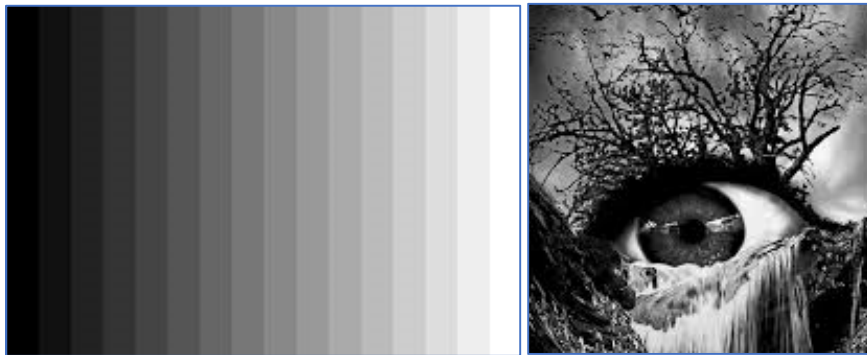


Figure 1-1: A) Grayscale and B) Grayscale Image

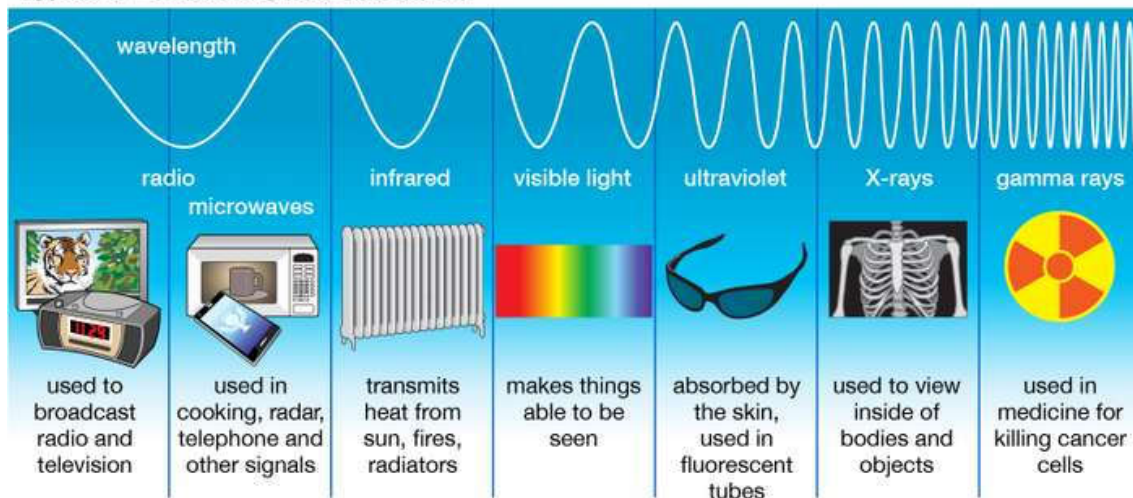
In function  $f(x, y)$ ,  $x, y$  represent the spatial plane (representation in 2D space) and value of  $f(x, y)$  represents the intensity of light or value of gray scale at that point i.e. 100. A digital image is one that has discrete values for  $x, y$ , and  $f$ . It means that each next pixel is located at the difference of one in either direction (horizontal or vertical) and number of values of  $f$  are discrete. The values of  $f$  are also called as gray levels where each level is at discrete distance from other. Digital image processing refers to processing a digital image using digital machine i.e. computer. Each value in an image is called **image element** or **picture element** or **pixel** or simply **pel**.

There are multiple fields that involve image processing like *Digital Image Processing*, *Computer Vision*, and *Medical Image Analysis*. We cannot draw clear boundaries among these fields however we can categorize image processing based on granularity of different features or type of task that perform with images.

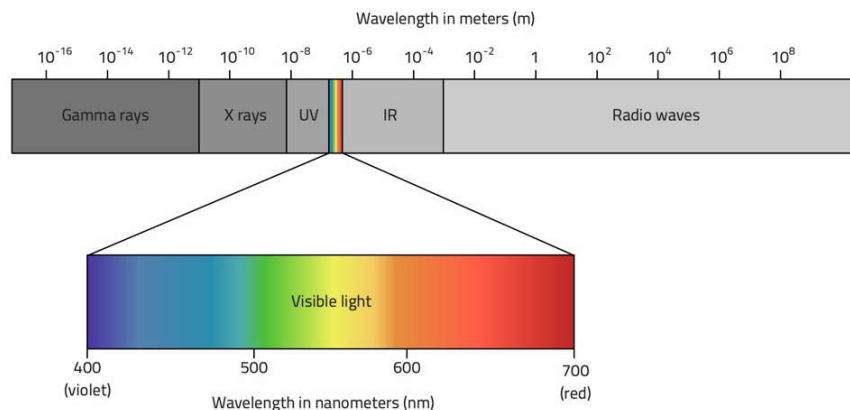
## 1.2 Electromagnetic Spectrum (EM Spectrum)

EM Spectrum is the distribution of electromagnetic radiation according to their frequencies. All electromagnetic waves travel at the speed of light however their frequencies, wavelengths and photon energies vary. The waves with different range of frequencies are grouped in the form of bands based on their features like emission, transmission and absorption. A group of specific frequencies is called a band and there are multiple bands in the electromagnetic spectrum. Bands are also defined based on their type of applications and there are no specific boundaries between the bands.

**Types of Electromagnetic Radiation**



**Figure 1-2: Electromagnetic Spectrum**



**Figure 1-3: EM spectrum and band frequencies**

## 1.3 Applications of Digital Image Processing

There is large variety of digital image processing applications. It is difficult to provide a comprehensive list. However according to different bands of EM spectrum, few of them are listed below:

### 1.3.1 Gamma Ray Imaging

Nuclear medicine and astronomical applications are prominent in this area. Positron emission tomography (PET), Single positron Emission tomography (SPECT). 2D and 3D images can be produced using these imaging methods or modalities.

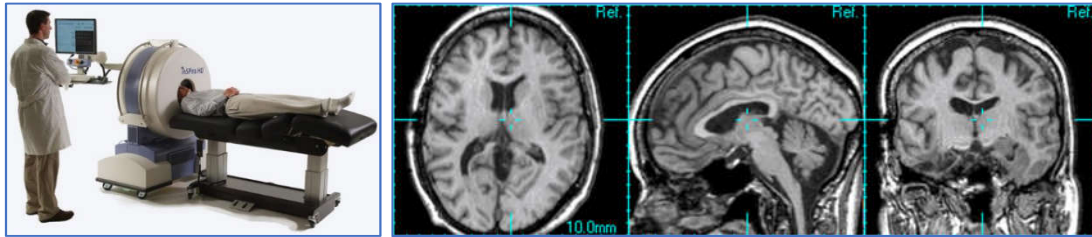


Figure 1-4: A) MRI imaging machine B) Brain MRI

There are various applications of Gamma ray imaging. Few of them are listed below:

- *Disease Diagnosis*: Positron emission tomography (PET) scans
- *Detection of precious stones* i.e. conversion of white topaz to blue topaz
- *Industrial uses* in refining, mining, chemicals, food, soaps and detergents, pulp, paper, water and oil industries, for the measurement of levels, density, and thicknesses
- *Trade vehicle analysis*: it is the application in which containers are checked using gamma rays to visualize their inner contents

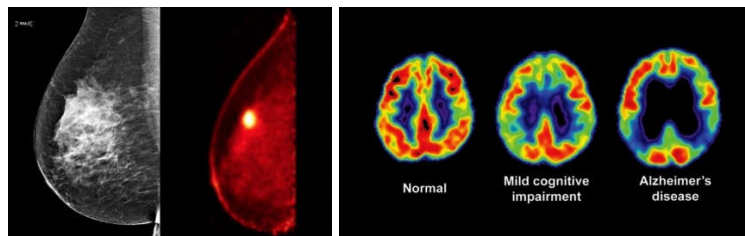


Figure 1-5: A) Breast Cancer Detection B) Brain Disease Detection

### 1.3.2 X-Ray Imaging

X-ray imaging is a well-known application. Such images are used in medical as well as industry and astronomy.

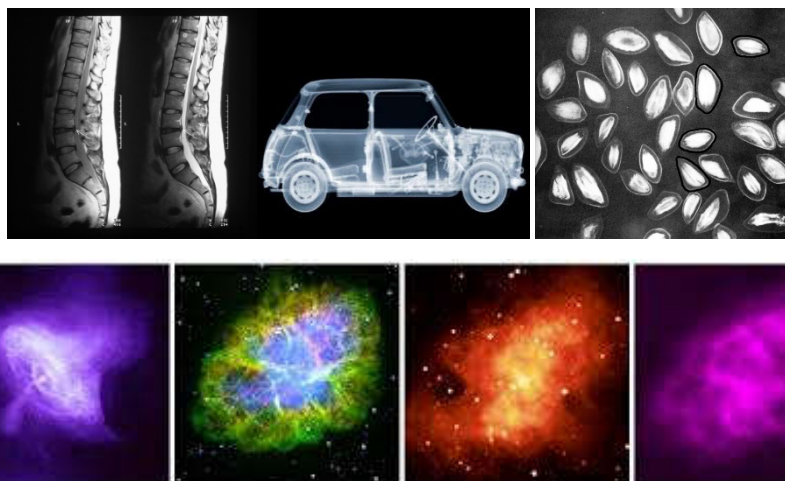


Figure 1-6: X-Ray imaging A) Spine X-ray B) Car X-ray C) Forest Seeds D) Space X-rays

Few of the uses are listed here:

- *Projectional radiography*: It is the process of producing two-dimensional images using x-ray radiation

- *Computed Tomograph*: Slices of specific areas of the body are obtained from a series of two-dimensional X-ray images taken in different directions. These cross-sectional images can be combined into a three-dimensional image of the inside of the body and used for diagnostic and therapeutic purposes in various medical disciplines.
- *Fluoroscopy*: It is the process to get the moving images of internal body organs using fluoroscope. In this method, an X-ray imaging intensifier is used along with CCD video camera that captures the moving pictures of human body and plays them on monitor.

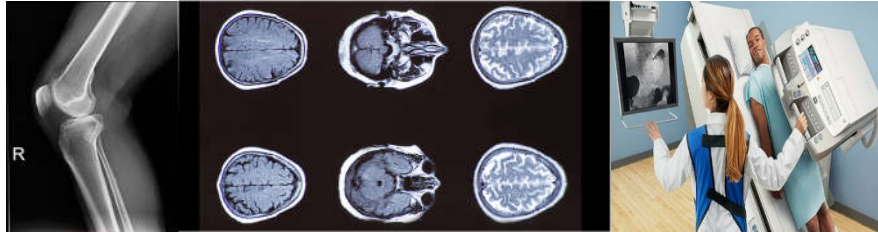


Figure 1-7: A) Plain x-ray of human knee B) Human head CT Scan C) Fluoroscopy

### 1.3.3 Imaging in Ultra Violet Band

These applications include lithography, industrial inspection, microscopy, lasers, biological imaging, legal uses, forensic applications, and astronomical observations. There are two main categories of UV imaging: UV light and UV-fluorescence imaging. True ultraviolet (UV) imaging inspection isn't used often in machine vision. However, as UV-sensitive cameras and UV-emitting light sources, particularly LED lighting, have become widely available and less costly, new applications are emerging.

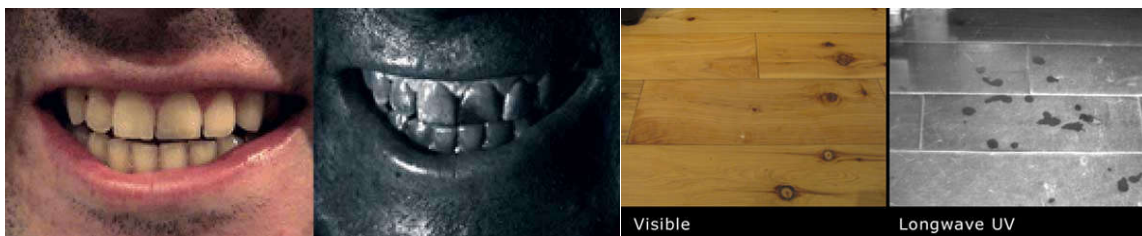


Figure 1-8: A) Visible band Image B) Ultraviolet band image C) Room floor and dirt spots on it

### 1.3.4 Imaging in Visible and Infrared Band

Compared to all other bands, visible band has lot more imaging applications. In most of the cases, imaging in visible and infrared bands is used combinedly. Few of such applications are listed below:

- *Personal Uses*: We, in this era, collect our pictures at difference occasions and keep them as memories. Selfies are the best example now a days.
- *Entertainment*: This is the biggest application domain of visible band imaging. We capture our own images, pictures of our loved ones and natural scenes. Moving pictures is another big application domain.
- *Microscopy*: A processing of visualizing very small objects that are difficult to be viewed with naked using specialized instruments like microscopes is called the microscopy. Microscopy has three branches: optical, electron and scanning probe microscopy.
- *Astronomy*: Photography of astronomical objects is known as astrography. Special digital cameras are used with long exposure to space in order to capture the details of required objects.



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- *Remote sensing*: is the acquisition of information about an object or phenomenon without making physical contact with the object. In this imaging sensors are used to measure the reflected sunlight. The measured light is converted into intensity that finally forms the image.
- *Industry*: Almost all type of industry uses photography in one or other aspect. The use may include marketing, industrial inspection, product design and process engineering.
- *Law enforcement*: Last but not the least, law enforcement bodies like police, court, investigators and lawyer make frequent use of imagery



**Figure 1-9: A) Personal Photo B) Entertainment C) Blood microscopy image D) Astronomical object E) Landsat 8 image of Southampton, UK E) Imaging in industry F) Imaging in Law**

Infrared radiation extends from the nominal red edge of the visible spectrum at 700 nanometers (nm) to 1 millimeter (mm). There are multiple uses of infrared that may include:

- *Night Vision*: Human eye cannot see in night however using night vision cameras, we can capture the images in dark. There are many areas where “seeing” through dark is required like military uses, house safeguarding and auto vehicle driving in night.
- *Thermography*: In thermal imaging temperature difference between foreground and background is measured. To see in night, thermal imaging cameras are used. Thermal imaging cameras are widely used to complement new or existing security networks, and for night vision on aircraft.
- *Hyperspectral imaging*: Human eye can only perceive three bands 1) red – the long wavelength band, green – the medium wavelength band and red – the short wave length band. Spectral imaging divides the spectrum in many more bands even beyond the visible band. Hyper spectral imaging covers a wide range of wavelength using continuous spectral band.
- *Spectroscopy*: It is study of interaction between matter and electromagnetic radiations. Spectroscopy is commonly used in scientific research areas of physics, chemistry and astronomy.
- *Meteorology*: It is a wider branch however it mainly focuses on weather forecasting using visual imagery.

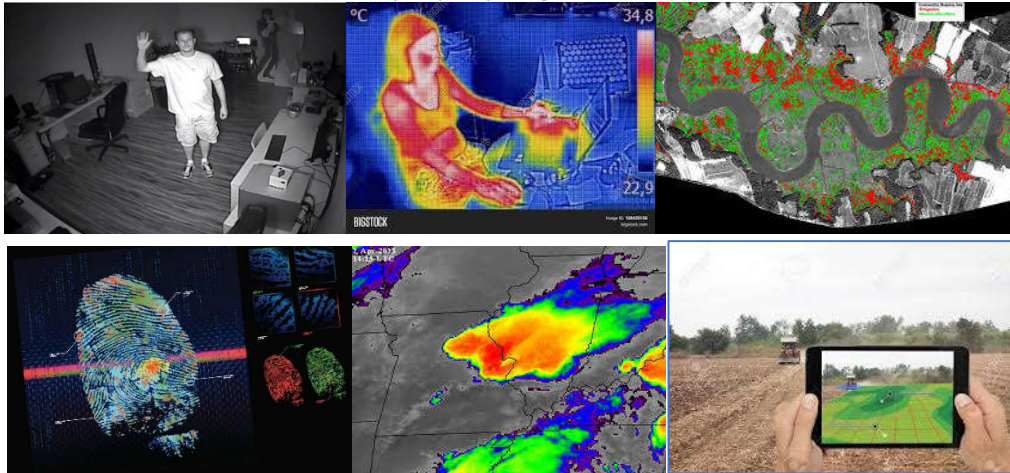


Figure 1-10: A) Infrared night vision B) Thermography C) Hyperspectral Image D) Fingerprint spectroscopy E) Infrared in Agriculture.

## 1.4 Fundamental Steps in Digital Image Processing

There are multiple steps involved in digital image processing. We list these steps in sequence here however it is not necessary that an application follows these steps in same order or follow all steps.

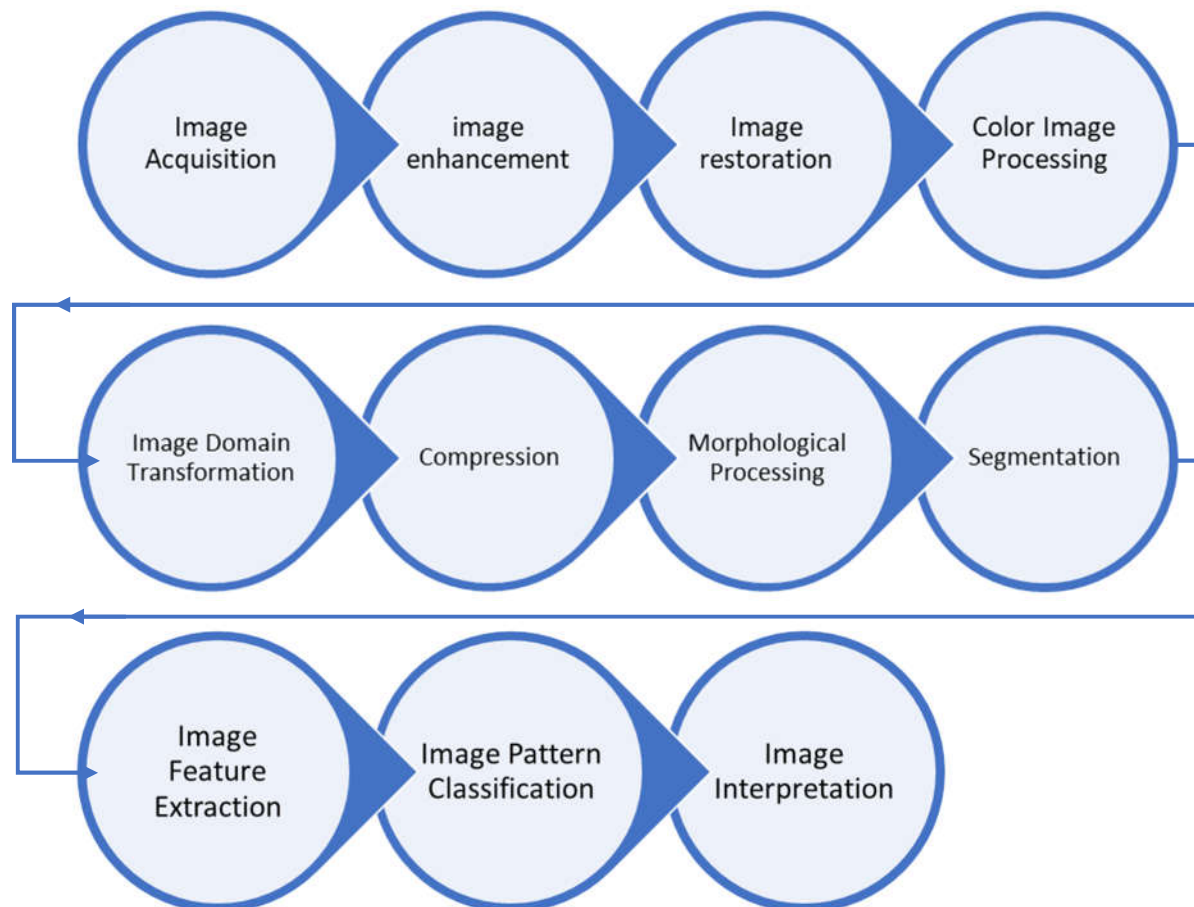


Figure 1-11: Image Processing pipeline

## 1.5 Components of Image Processing System

A computer system that can process the images consists of various components and these may vary from application to application.

- **A computer system:** Normal or specialized computer. For this course, your laptop may work
- **Image display devices:** Specialized screens are required for professional work however your current system will be good for current requirement.
- **Mass storage devices:** Normally image processing professionals require lot of mass storage and if your system has at least few GB space, it will be ok.
- **Image processing specialized software:** We may need some specialized software like python, PyCharm and other relevant libraries.
- **Image processing specialized hardware:** Normally your current VGA card and processor are ok to work with this manual. However, GPUs are now common in image processing applications.
- **Hardcopy:** you may need a printer to get the print of your work.

## 1.6 OpenCV and Image Processing

A software *toolkit* is collection of libraries that help you to learn, experiment and develop software for a particular domain. For example, in image processing, there are many algorithms that we apply on images to perform different tasks on images like quality enhancement, sharpening, information extraction and segmentation. All these algorithms are programmed by experts of that domain and are made available for others to use. Although there are many image processing toolkits available in market however two most popular applications are:

- OpenCV
- MATLAB



### 1.6.1 OpenCV

OpenCV stands for Open Computer Vision or most precisely Open Source Computer Vision Library. There are two main objectives behind the development of OpenCV:

- To provide common infrastructure for computer vision applications
- To accelerate the use of machine vision in commercial software products

At present, the library contains 2500 image processing and computer vision algorithms coded. According to opencv.org there are more than 47,000 registered users. This library is being used by researchers, academia, govt. bodies and commercial companies like Google, Yahoo, Microsoft, Intel, IBM, Sony, Honda and Toyota. The library has support for C++, Java, Python and MATLAB. It can be run on Windows, Linux and Android OS. According to opencv.org:

*“Modern Graphical Processing Unit (GPU) accelerators has become powerful and featured enough to be capable to perform general purpose computations (GPGPU). It is a very fast-growing area that generates a lot of interest from scientists, researchers and engineers that develop computationally intensive applications. Despite of difficulties reimplementing algorithms on GPU, many people are doing it to check on how fast they could be. To support such efforts, a lot of advanced languages and tool have been available such as CUDA, OpenCL, C++ AMP, debuggers, profilers and so on.*

*Significant part of Computer Vision is image processing, the area that graphics accelerators were originally designed for. Other parts also suppose massive parallel computations and often naturally*



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map to GPU architectures. So, it's challenging but very rewarding to implement all these advantages and accelerate OpenCV on graphics processors"

Following Figure 1-12: CPU vs GPU, gives a high-level view of CPU and GPU.

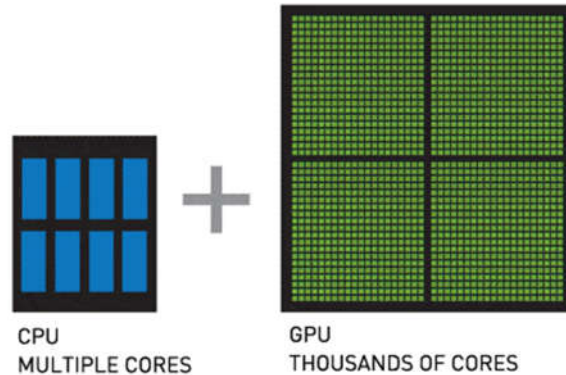


Figure 1-12: CPU vs GPU

And when working with such high number of processing cores, massively parallel processing is required that is being built in OpenCV. C++ is main development language for OpenCV.

### 1.6.2 Software Required for this book

We will be using open source software that are freely available. Here is the list:

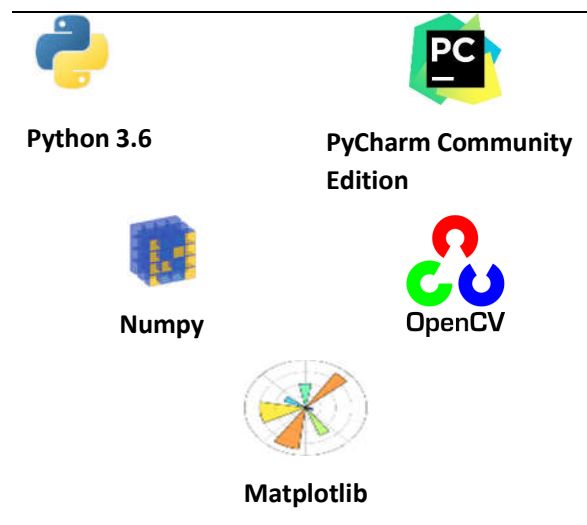


Figure 1-13: Software Used in this Book

It is sometime complex task to install and configure the tools mentioned in Figure 1-13: Software Used in this Book. In order to make the learning process easy, we have provided a detailed tutorial on installation and configuration of these tools in Append-A.

### 1.6.3 Support and Debugging

If you write an OpenCV program and need to debug it do the followings:

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- At first try to troubleshoot the problem using OpenCV documentation and tutorials. The documentation is provided at <https://docs.opencv.org/>. There are many versions of OpenCV so when you are going to find something, search in the documentation of OpenCV version that you have installed. In this book we are using OpenCV version 4.1.1. You can also download the documentation and make available offline. To be a good user, make yourself familiar with library documentation.
- If it doesn't help, search for an answer or ask a question at OpenCV Answers <https://answers.opencv.org/questions/> or on Internet.
- Keep on visiting OpenCV Answers and as you learn the library, do answer at the forum.

## 1 1.7 Problems and Exercises

- 2 1. What is electromagnetic spectrum? Describe its different bands and their properties.
- 3 2. What are characteristics of large wavelength and short wave length bands? How these different bands
- 4 are useful in different type of applications
- 5 3. Considering the medical imaging applications which bands are useful and what are various
- 6 modalities/cameras used for medical imaging.
- 7 4. Military applications are very important in any country. List the names of few military applications,
- 8 electromagnetic bands used and their importance in this context.
- 9 5. Industry is the largest area that is benefitting with digital image processing. Write a report that
- 10 describes the imaging applications in this domain.
- 11 6. Crops cultivation and food processing are two fields related to human surveillance and health. How
- 12 imaging technology and digital image processing can help? Write a report.
- 13 7. What are fundamental steps in image process? Write and explain them. Is it necessary to perform all
- 14 steps in a particular application?
- 15 8. What are different tools and devices that you need to perform the task of digital image processing.
- 16 List and explain the role of each tool.
- 17 9. Prepare a list of software tools which can be used for digital image processing. Compare them using
- 18 their different characteristics and comment them critically.
- 19 10. What is the difference between CPU and GPU? List the names of few GPU manufacturers and their
- 20 popular GPU models.
- 21 11. How a GPU can boost the computation of your algorithm and why it is necessary to do big data
- 22 analysis?