High Level Design (HLD)

Knee MRI Classification

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Contents

Abstract

Magnetic resonance imaging (MRI) of the knee is the preferred method for diagnosing knee injuries. However, interpretation of knee MRI is time-intensive and subject to diagnostic error and variability. An automated system for interpreting knee MRI could prioritize high-risk patients and assist clinicians in making diagnoses. Deep learning methods, in being able to automatically learn layers of features, are well suited for modelling the complex relationships between medical images and their interpretations.

1. Introduction

1.1. Why this High-Level Design Document?

The purpose of this High-Level Design (HLD) Document is to add the necessary detail to the current project description to represent a suitable model for coding. This document is also intended to help detect contradictions prior to coding and can be used as a reference manual for how the modules interact at a high level.

1.2. Scope

The HLD documentation presents the structure of the system, such as the predictive model used, application architecture (layers), application flow (Navigation), and technology architecture. The HLD uses non-technical to mildly technical terms which should be understandable to the administrators of the system.

1.3. Overview

The HLD will:

- present all of the design aspects and define them in detail
- describe the user interface is implemented
- describe the software interfaces
- include design features and the architecture of the project

2. Project Description

2.1. Introduction

The knee is one of the largest and most complex joints in the body. The knee joins the thigh bone (femur) to the shin bone (tibia). The smaller bone that runs alongside the tibia (fibula) and the kneecap (patella) are the other bones that make the knee joint. Tendons connect the knee bones to the leg muscles that move the knee joint. Ligaments join the knee bones and provide stability to the knee:

- Anterior Cruciate Ligament (ACL) prevents the femur from sliding backwards on the tibia.
- Posterior Cruciate Ligament (PCL) prevents the femur from sliding forward on the tibia
- Medial and Lateral Collateral Ligaments prevent the femur from sliding side to side.
- Two C-shaped pieces of cartilage called the medial and lateral menisci to act as shock absorbers between the femur and tibia.

Normal knee appears as shown in the MRI Scan:

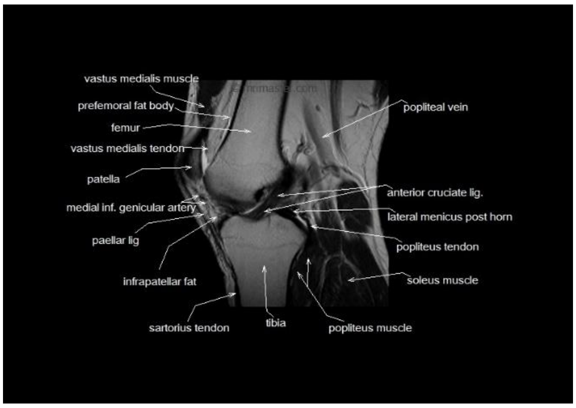

Figure 1 - MR knee cross section-Source: mrimaster.com

The abnormalities that can occur in the above ligaments can be understood by the following figures

ACL Tear

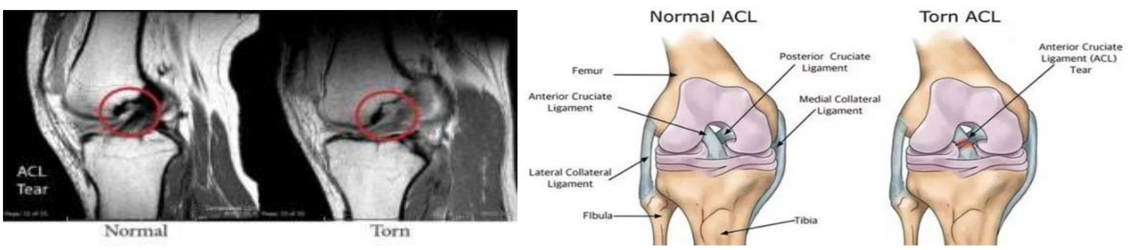

Figure 2-ACL Injury-Source: CorePhysio.com& pristyncare.com

Meniscus Tear

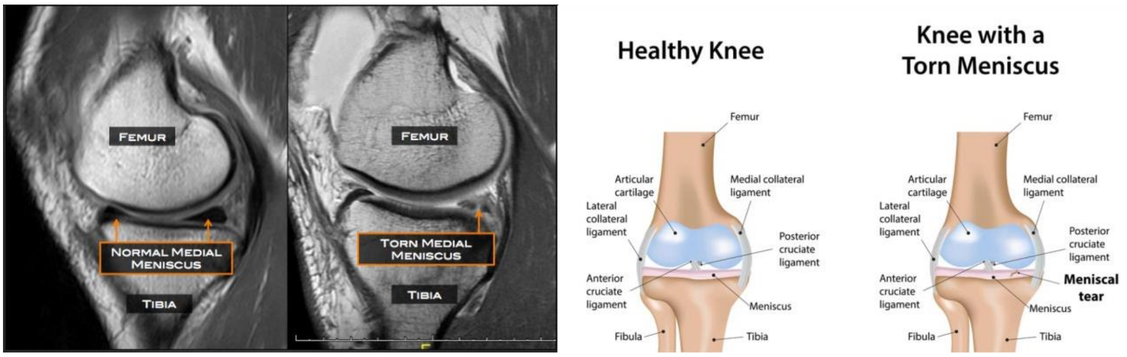

Figure 3 Meniscus-MCL, Source: braceworks.ca & paindoctor.com

PCL Tear

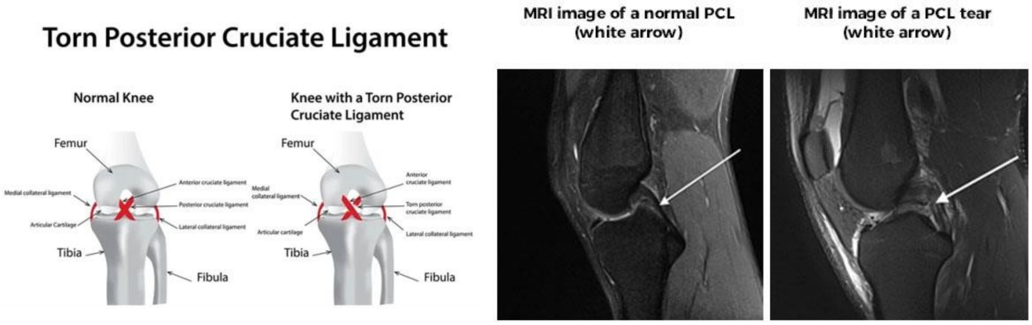

Figure 4- PCL, Source: ossurwebshop.co.uk & yorkshirekneeclinic.com

Magnetic Resonance Imaging (MRI) of the knee uses a powerful magnetic field, radio waves and a computer to produce detailed pictures of the structures within the knee joint. It is typically used to help diagnose or evaluate pain, weakness, swelling or bleeding in and around the joint and it can help determine whether you require surgery. In order to better confront the ever-growing workload of musculoskeletal (MSK) radiologists, automated tools for patients' triage are becoming a real need, reducing delays in the reading of pathological cases.

Abnormal:

Osteoarthritis

Osteoarthritis is the most common form of arthritis, affecting more than 8.75 million people in the UK. Knee osteoarthritis is defined by degeneration of the knee's articular cartilage—the flexible, slippery material that normally protects bones from joint friction and impact. The condition also involves changes to the bone underneath the cartilage and can affect nearby soft tissues.

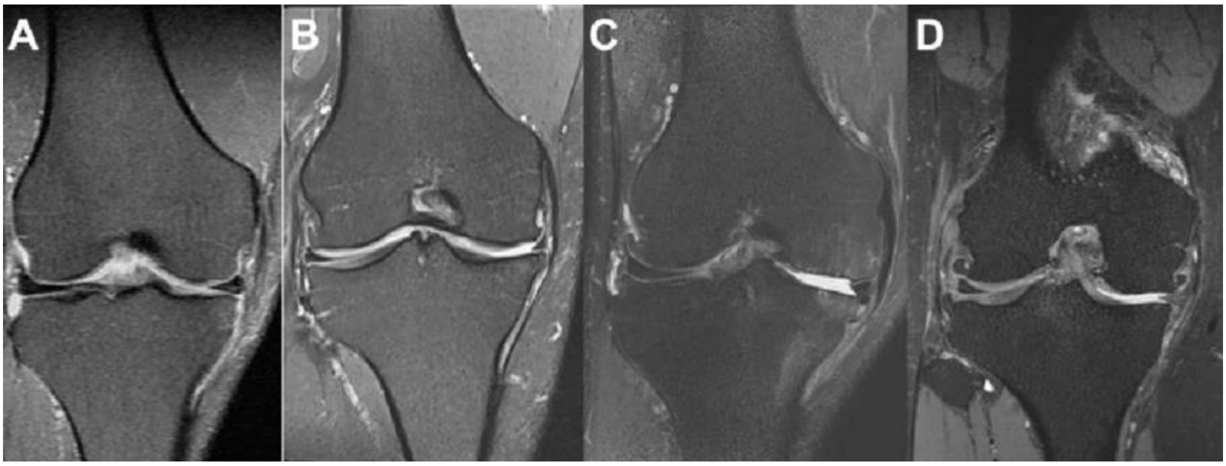

Figure 5-Osteoarthritis, Source: researchgate.net

(A) grade 0 (none), (B) grade 1 (small size osteophytes in lateral femur and tibia), (C) grade 2 (medium size osteophytes in lateral femur and tibia), and (D) grade 3 (large size osteophytes in lateral femur and tibia).

Iliotibial band syndrome

Iliotibial band syndrome occurs when the connective tissue (ligament) extending from the pelvic bone to the shinbone becomes so tight that it rubs against the thigh bone. Distance runners are especially susceptible to it. It occurs when the IT band becomes tight, irritated, or inflamed. This tightness causes friction on the outside of the knee when bending, which is painful.

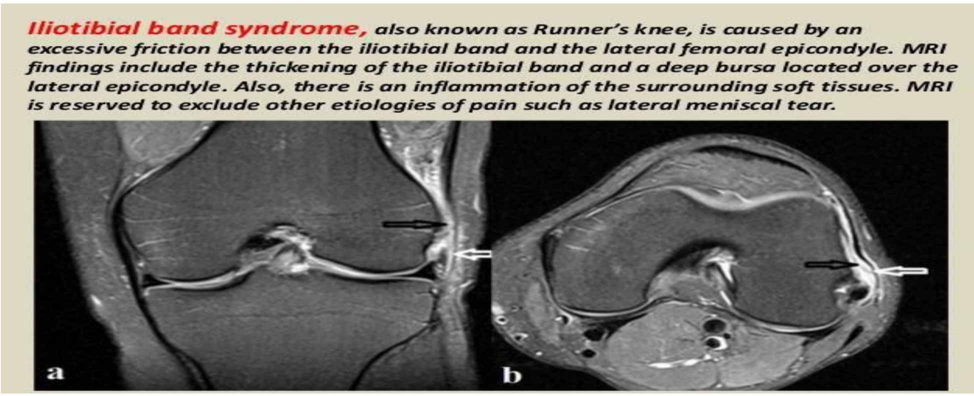

Figure 6-Iliotibial band Syndrome

Contusions

Knee contusions are the result of heavy impact to the knee, usually from a blow or fall that damages the soft tissues (such as the blood vessels) or bone. Following impact, blood spills into the tendons, tissue, and muscles in your knee. A knee contusion can also be accompanied by scrapes and skin tears.

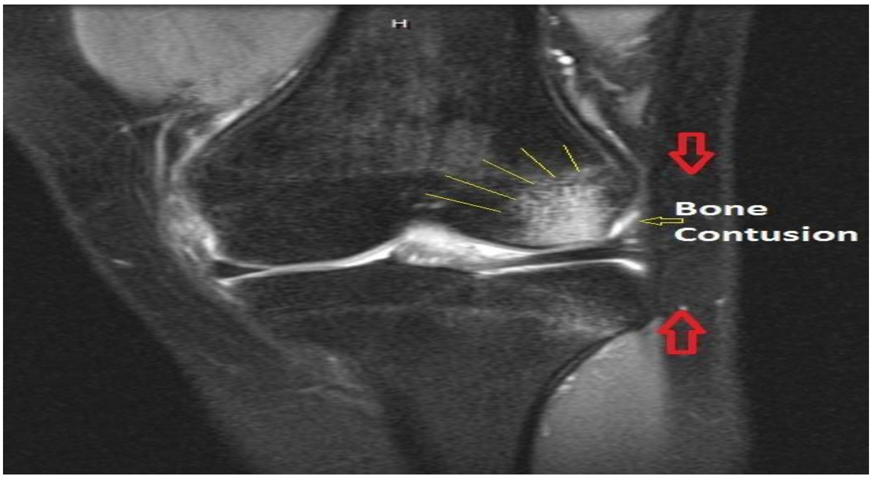

Figure 7-Contusion, source:orthokids.org

Plica

A plica is a fold in the thin tissue that lines your knee joint. Most people have four of them in each knee. They let you bend and move your leg with ease. One of the four folds, the medial plica, sometimes gets irritated from an injury or if you overuse your knee. This is known as plica syndrome.

This is often caused by exercises that require you to frequently bend and straighten your knee, such as running, biking, or using a stair-climbing machine. An injury from an accident, such as a fall or car accident can also cause plica syndrome.

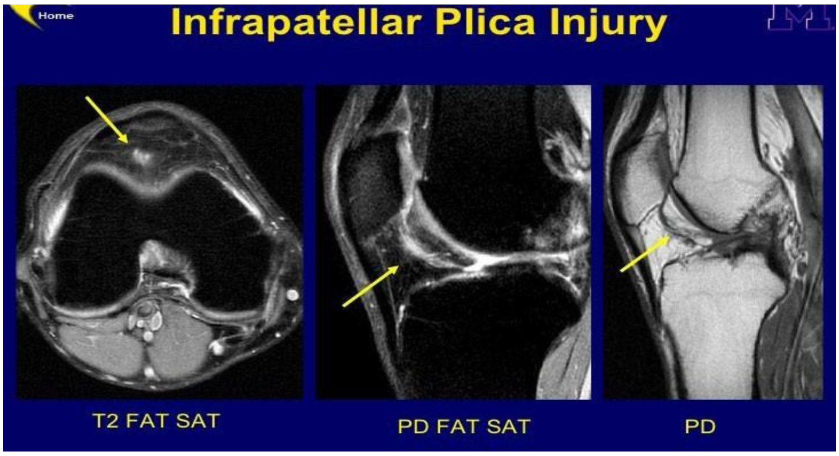

Figure 8-Anterior knee pain,Source:slidesharecdn.com

Fracture

A knee fracture is a type of injury involving the patella, or the bone that makes up the front of your knee (also known as the kneecap). It can be as mild as a small, partial crack in the bone or as severe as a complete break from the top of the kneecap to the bottom.

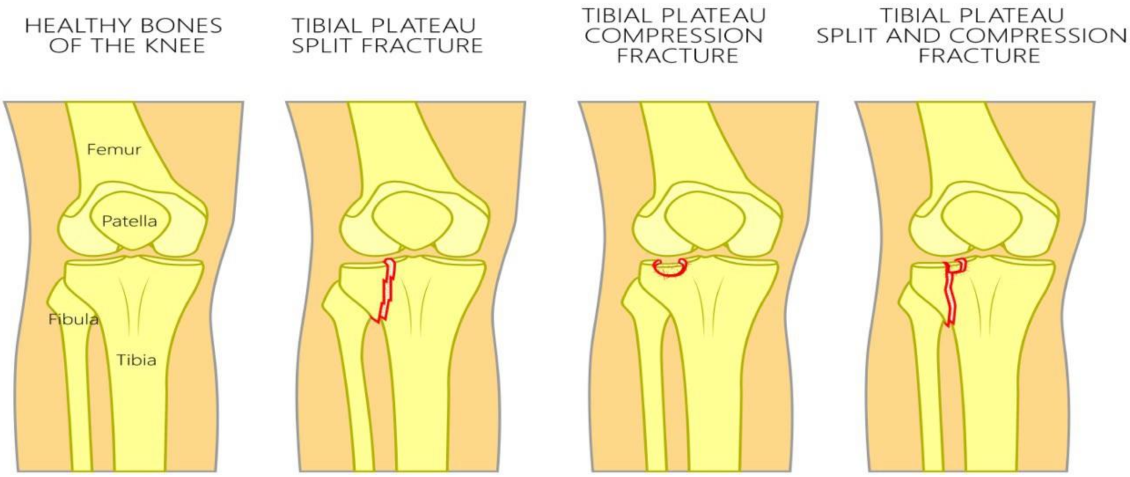

Figure 9-Fracture, Source: dreamstime.com

Figure 10-Tibial Stress Fracture

2.2 High-Level Objectives

1. To enable reading/loading of MRI Image by the user.
2. To pre-process the MRI image for enhanced quality before further processing.
3. To classify the image into normal and abnormal using Deep Learning Techniques
4. If abnormal, predicting the type and location of the injury.
5. To perform statistical analysis of the results and display them in a user-friendly manner.

The project can be divided into multiple phases:

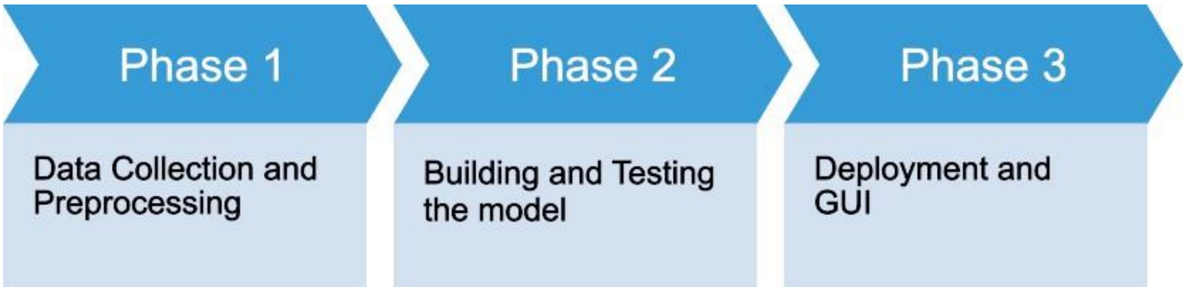

Figure 11-Project phases

2.3 MRNET Dataset

The dataset is taken from the Stanford University School of Medicine, it has been made publicly available by researchers from 2018. It consists of 1,370 knee MRI exams performed at the Stanford University Medical Centre.[1]

The dataset contains MRIs for:

i) 1,104 (80.6%) abnormal exams

ii) 319 (23.3%) ACL (anterior cruciate ligament) tears

iii) 508 (37.1%) meniscal tears

2.4 Tools Used

1. PyCharm IDE – For Python
2. Tableau/Power BI for Dashboard creation
3. Flask for backend development
4. GUI developed with HTML and CSS. – To get user input and display output

Figure 12-Tools

2.5 Constraints

The Knee MRI classification system must be user friendly, as automated as possible and users should not be required to know any of the workings.

2.6 Program flow

The figure below shows the high-level flow of the proposed project.

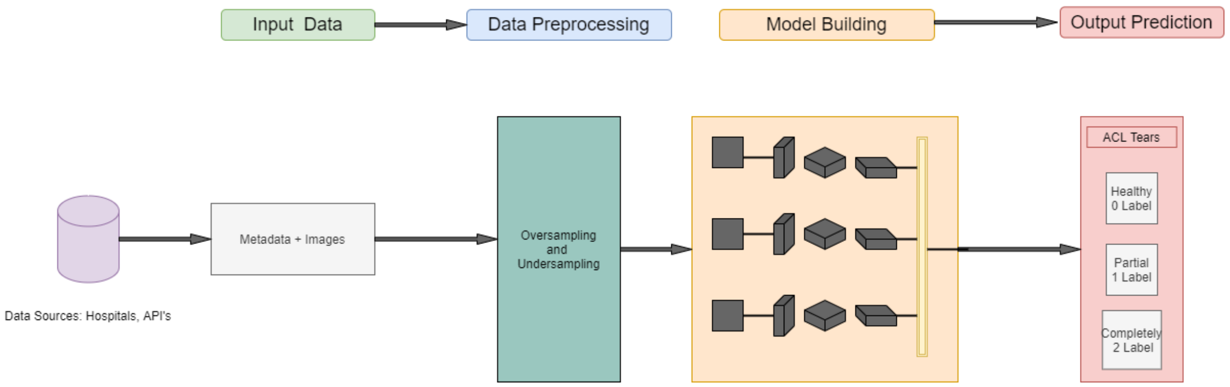

Figure 13-ProgramFlow

2.5.1 Input Layer

Will get input details such as name, age, and relevant details from the user and gets the image uploaded through a GUI.

2.5.2 Data Pre-processing Layer

- Responsible for fine-tuning the images to enable better prediction.
- Data Augmentation can be done at this stage.

2.5.3 Model Building

To begin with, it is proposed to start with a pre-trained CNN model through transfer learning. Subject to change.

2.5.4 Output Prediction

The output predicted can be displayed to the user with the help of UI.

2.6 Details of DL Model

The DL model is referred from a Research Article published in the Radiology Artificial Intell Journal. The article is titled as Fully Automated Diagnosis of Anterior Cruciate Ligament Tears on Knee MR Images by Using Deep Learning[2]. They have developed a Fully Automated ACL Tear Detection System. This model will help us achieve our objectives.

The proposed deep learning-based ACL tear detection system consisted of three separate CNN architectures.

1. The first part classifies the images that show Knee injuries from the entire MR image dataset. We can use
   1.1. Alex Net (ImageNet Classification with Deep Convolutional Neural Networks, Alex Krizhevsky University of Toronto kriz@cs.utoronto.ca Ilya Sutskever University of Toronto ilya@cs.utoronto.ca Geoffrey E. Hinton University of Toronto hinton@cs.utoronto,2012),
   1.2. VGG-16(ImageNet Large Scale Visual Recognition Challenge Olga Russakovsky* · Jia Deng* · Hao Su · Jonathan Krause · Sanjeev Satheesh · Sean Ma · Zhiheng Huang · Andrej Karpathy · Aditya Khosla · Michael Bernstein · Alexander C. Berg · Li Fei-Fe2014)

   1.3 ResNet (Deep Residual Learning for Image Recognition Kaiming He, Xiangyu Zhang, Shaoqing Ren, Jian Sun2015)

   1.4 Faster R CNN (Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks Shaoqing Ren∗ Kaiming He Ross Girshick Jian Sun Microsoft Research {v-shren, kahe, rbg, jiansun}@microsoft.com Abstract State-of-the-art object detection networks depend on region proposal algorithm2016)

   1.5 DenseNet (Densely Connected Convolutional Networks Gao Huang, Zhuang Liu, Laurens van der Maaten, Kilian Q. Weinberger CVPR 2017).

2. The second part isolates the anomalous region that contains the injury to narrow down the range of information. We can use object detection models like YOLOv4(YOLOv4: Optimal Speed and Accuracy of Object Detection Alexey Bochkovskiy, Chien-Yao Wang, Hong-Yuan Mark Liao Submitted on 23 Apr 2020)

3.The third part evaluates the isolated injuries on the image sections obtained from step 2 to determine the presence or absence of an injury. This step will help us get a Heatmap showing the probabilities of the injury.

These three CNNs are connected in a cascaded fashion to create a fully automated processing pipeline, as shown in the following figure.

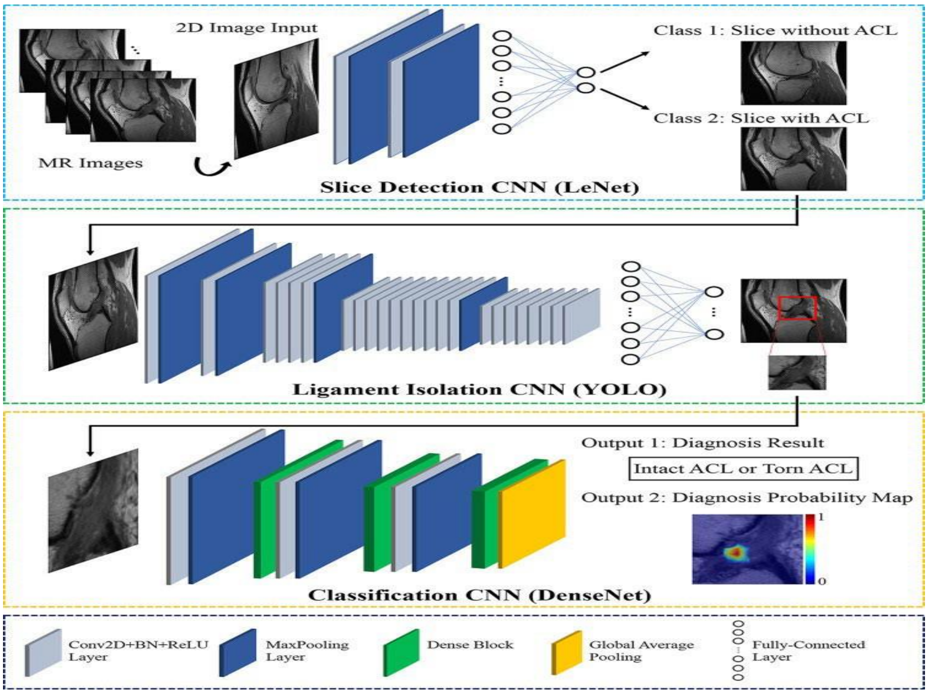

Figure 14-DL-Model

2.6.1 Performance Metrics

We can use the sensitivity, specificity, and ROC-AUC for determining the performance of the model.

2.7 Expected output

The output product will be a package that would take the input of the MRI scans and will give the user the prediction of the type of knee injury and a heatmap of the location of the injury. The user interface will consist of:

2.6.1 Landing Screen

- Brief about the procedure
- User Login
- Creating New Account

2.6.2 User Session Screens

- Input page: Taking user input for MRI Scans
- Output Page: Type of injury with confidence level and classified images of Coronal, Sagittal and Axial scans showing heatmap for the location of the injury.

2.6.3 Sample GUI

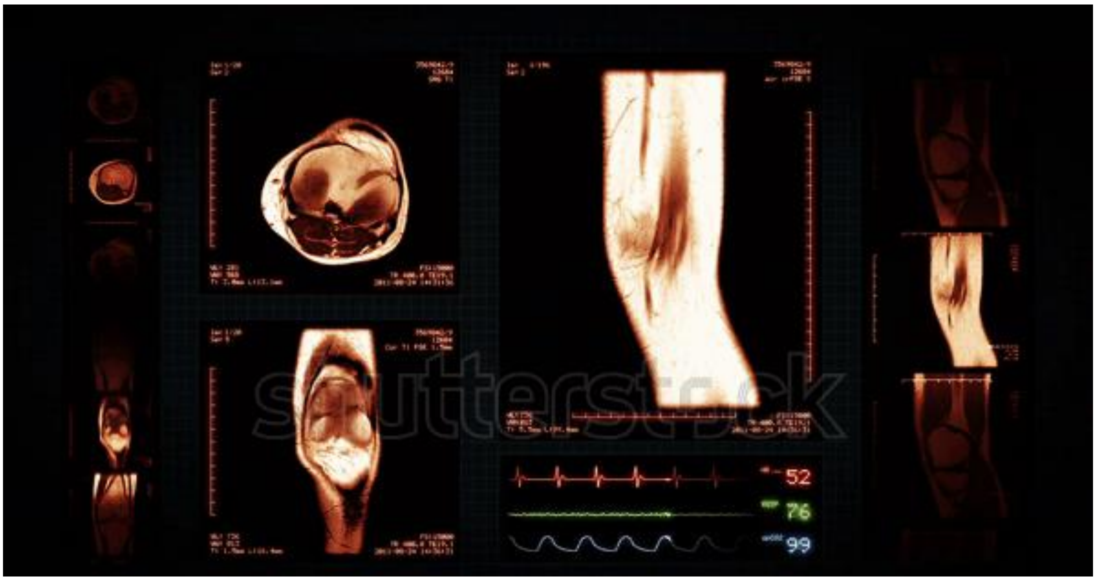

Figure 15-Sample GUI

3. References

1. “MRNet Dataset.” Stanford ML Group, https://stanfordmlgroup.github.io/competitions/mrnet/

2. Liu, F., Guan, B., Zhou, Z., Samsonov, A., Rosas, H., Lian, K., Sharma, R., Kanarek, A., Kim, J., Guermazi, A., & Kijowski, R. (2019). Fully Automated Diagnosis of Anterior Cruciate Ligament Tears on Knee MR Images by Using Deep Learning. Radiology. Artificial intelligence, 1(3), 180091. https://doi.org/10.1148/ryai.2019180091