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NUST COLLEGE OF

ELECTRICAL AND MECHANICAL ENGINEERING

Osteo-Doc AI Based Solution for Knee Osteoarthritis Grading and Exercise Management

A PROJECT REPORT

DE-40 (DC&SE)

Submitted by

NS HAIDER MASOOD

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BACHELORS

IN

COMPUTER ENGINEERING

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PESHAWAR ROAD, RAWALPINDI

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DECLARATION

We hereby declare that no portion of the work referred to in this Project Thesis has been submitted in support of an application for any other degree or qualification of this for any other university. If any act of plagiarism found, we are fully responsible for every disciplinary action taken against us depending upon the seriousness of the proven offence.

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ABSTRACT

Various deep learning frameworks are being proposed for autonomous detection of diseases to contribute toward telemedicine, moreover, despite the low doctor to patient ratio, such algorithms aid physicians in tracking the disease with more accuracy. According to WHO, Osteoarthritis has been declared the most common form of arthritis, and additionally, it is one of the significant reasons for physical disability in older age.

Different deep learning framework-based approaches exist for the evaluation of knee osteoarthritis, but none of them incorporates the feedback or symptoms of the patients.

The clinical approach to diagnosing Knee Osteoarthritis does not primarily depend on radiographic images; instead, it includes other factors like asking patients about their daily activities and using a goniometer to check their flexion angle. Thus, mapping our project based on these clinical approaches, we have proposed a tri-weight age classification model, i.e. a hybrid approach for grading osteoarthritis using structural features from X-Ray images, KOOS questionnaire and flexion angle.

Moreover, we conducted a comparison of various deep learning models on our dataset and achieved the highest accuracy of 89.29% for RESNET 152 V2 and INCEPTION RESNET V2.

To make the solution easily accessible to the general public and targeted audience, we have introduced an Android Application that incorporates all the above parameters and provides patients with insights into their joint health scores and the progress dashboard of their daily activities and knee score.

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Chapter 1: Introduction

1.1 Introduction

Health apps are the applications developed to aid end-users in their day to day life by keeping track of their health conditions and providing a bird's eye view of different stats like physical activities, diet and sleep so that they get a holistic view of their health condition. The psychological aspect of these apps cannot be ignored as they provide one with that feeling of control over their health conditions, and the user is more aware of different health metrics.

Many middle-aged men and women are affected by many bone diseases. These diseases either make them disabled or significantly affect the quality of their lives. These diseases also have a psychological toll as well as the patient is constantly under stress.

These diseases can be caused by some injuries, weight, gender, age, genealogical factors or poor posture. These diseases include permanent deformation of bones, pain in joints or other disabilities.

Some of the significant disorders include Osteoporosis, Fractures, Scoliosis, Paget's disease, Osteoarthritis, Rheumatoid arthritis, Gout and Bursitis. These diseases are often comorbid with more complex diseases such as certain neurological disorders, and some of these can have a significant effect on vital organs as the skeletal structure is compromised. Many people suffer from these diseases. Scoliosis alone affects nearly 6,000,000 - 9,000,000 in the US, while Osteoarthritis affects 32,500,000 million US adults. It is the most common type of arthritis.

Osteoarthritis has various treatments that can be used to improve the quality of ones life, but unfortunately, it cannot be reversed. The treatments range from the use of drugs to suppress the pain to various kinds of physical activities and therapies to help the patient perform his daily tasks with ease. The main issue identified by the medical practitioners is the mobility of the joint and maintaining a delicate balance between keeping the joint mobile and excessive mobility of the joint, as both lead to pain. Not keeping the joint mobile will cause the joint to lose its range of motion, and the patient will feel pain even during everyday movements. Overusing the joint will cause the joint to deteriorate at a much faster pace.

We proposed a solution after meeting various medical practitioners and healthcare providers catering for this joint health issue. Our proposed solution provides the end-user with a single digit representing the joint health and a log of recent activities to help the medical practitioner determine which activities are helping the patient and vice versa. Helping them devise a healthcare plan which helps improve one’s quality of life.

An Android platform is used to implement our research-based tri-weightage classification model. Which will enable the patients to track their joint health and give feedback to the medical service provider, track their treatment timeline, and also help the physician analyse and optimize his/her treatment based on the History of knee-health scores. The data gathered through the online platform will eventually help us to better improve the model by implementing state of the art data analysis and machine learning tools. This data will also help find disorder patterns among different ages, gender and regions and then predict activities beneficial for a particular class of patients.

The project's primary goal is to make Osteoarthritis patients respected members of society by providing an that is simple, accessible and has no alternative available in the market.

1.2 Motivation

Degenerative Joint Disorder (DJD) is another name for osteoarthritis (OA); it is a condition that usually affects middle-aged people when the cartilage in a joint becomes stiff and loses its elasticity. The hand, knee and spine are the most affected joints. Additionally, among all of them, knee arthritis comprises the majority of cases.

This disease has affected almost 9% of the global population. More than 32.5 Million US adults, i.e., 50% of Americans over 65, have radiological symptoms of osteoarthritis in one joint at least. According to an estimate, more than 20% of US adults will be 65 by 2030 and be at risk for osteoarthritis.

Arthritis is a serious medical condition. According to the CDC, one out of every four Americans (or 54.4 million) has arthritis; with this situation, the number is expected to increase to 78 million by 2040.

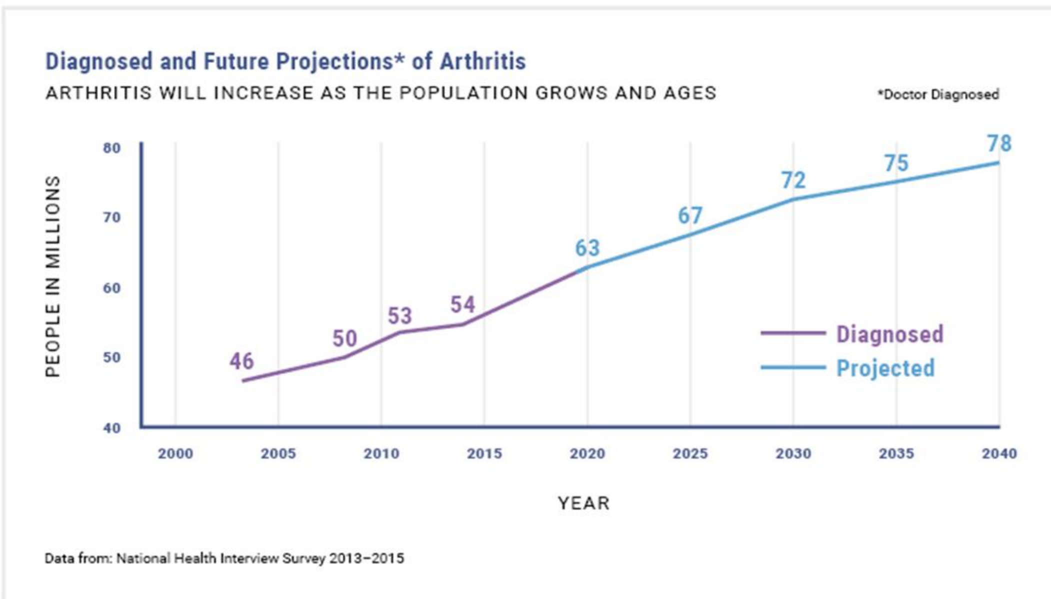


Figure 1: Future prediction of Osteoarthritis

Typical forms of arthritis (rheumatoid arthritis, osteoarthritis, and gout) contribute significantly to Australia's illness, disability, and pain. According to the Australian Burden of Disease Study 2015, musculoskeletal problems accounted for 13% of the total disease burden (about 611,300 disability-adjusted life years (DALY)). Osteoarthritis accounted for 19 % of the illness burden, rheumatoid arthritis accounted for 15%, and gout accounted for 0.9%. The remaining burden accounted for 'back pain and related problems (32%), other musculoskeletal conditions (33%).

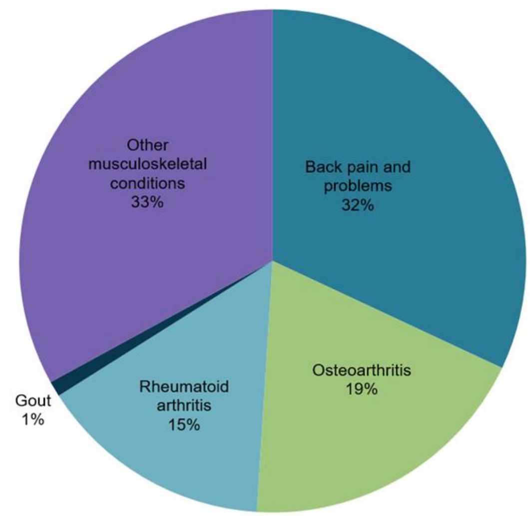


Figure 2: Pie chart of bone related diseases

Due to the discomfort and physical limitations associated with arthritis, it can have a substantial influence on a person's physical health.

In 2017–18, half of those aged 45 and up with arthritis (56 percent) reported 'moderate' to 'very severe' pain in the previous four weeks, which was 2.3 times higher than the general population (24 percent). Furthermore, nearly 2 in 5 (45 %) adults with arthritis aged 45 and above said their pain had interfered with their usual job in the previous four weeks from moderate to 'severe'.

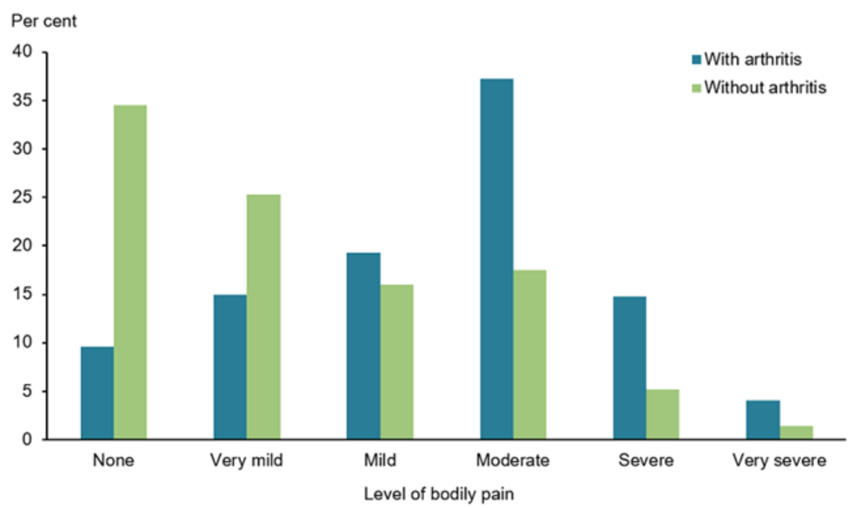


Figure 3: Pain severity graph

The burden of osteoarthritis is a severe and rising issue as 242 Million people worldwide have symptomatic and activity-limiting OA of the hip and knee. Osteoarthritis pain affects sleep, quality, mood and participation in everyday life, and it significantly limits a person's ability to manage other conditions, such as diabetes and hypertension. A third of people with OA have five or more chronic conditions and increase the risk of developing heart disease by 50% due to reduced levels of physical activity, combined conditions and adverse effects of medication.

Figure 4: Cost of Osteoarthritis

Osteoarthritis of the knee is also among the most common rheumatic disorders in the Asia-Pacific region, as in other regions of the world. According to studies, the prevalence of knee osteoarthritis (KOA) in China is 7.50 %, 10.9 %, and 13.6 %. It is believed to be 5.78 % in India and 10.20 % in Bangladesh, respectively. Knee osteoarthritis affects 28.0% of the urban population and 25.0% of the rural population in Pakistan.

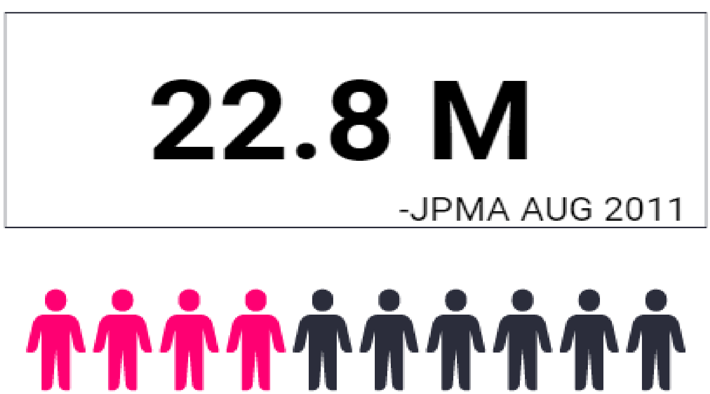


Figure 5: Number of OA patients in Pakistan

Recognizing the promising statistics, there is an urge to propose an autonomous framework capable of diagnosing and staging disease severity with ease of adoption and lessening the burden of specialists. Moreover, the proposed framework may aid in telemedicine to aid timely diagnosis that can assist the patients in taking precautionary measures prior to the severe condition.

1.3 Scope

The project aims to develop a complete solution to help and assist the patients suffering from Osteoarthritis in the comfort of their homes. The project mainly focuses on two parts, an Android Application and a digital goniometer. It is designed to comfort the users as it is an in-hand solution and can be carried around fairly quickly and operated without any assistance. The project's scope mainly revolves around the patients' pain points, like a low doctor-to-patient ratio, regular discomfort in visiting doctors/clinics, and no alternate way to track joint health. The android application allows patients to check their knee score by our tri-weightage classification model regularly. That takes a recent X-Ray image as the input to return the grade based on the KL grading system, and users would be required to fill the questionnaire depending on the current situation and enter flexion angle according to the digital goniometer. The application would output a computed score based on mathematical equations, ensuring that the experience is personalized for each patient. There will be a user dashboard which would maintain a log of the daily exercise activities by the users along with previously computed knee scores to give a holistic view of the knee joints without frequent visits to clinics.

The project encompasses the following objectives:

- To develop an Android Application for Tri-Weightage classification based on:
    - X-Ray Grading using AI Model
    - KOOS Questionnaire
    - Digital Goniometer
- To keep a log of relevant exercises performed by patients
- To generate progress reports

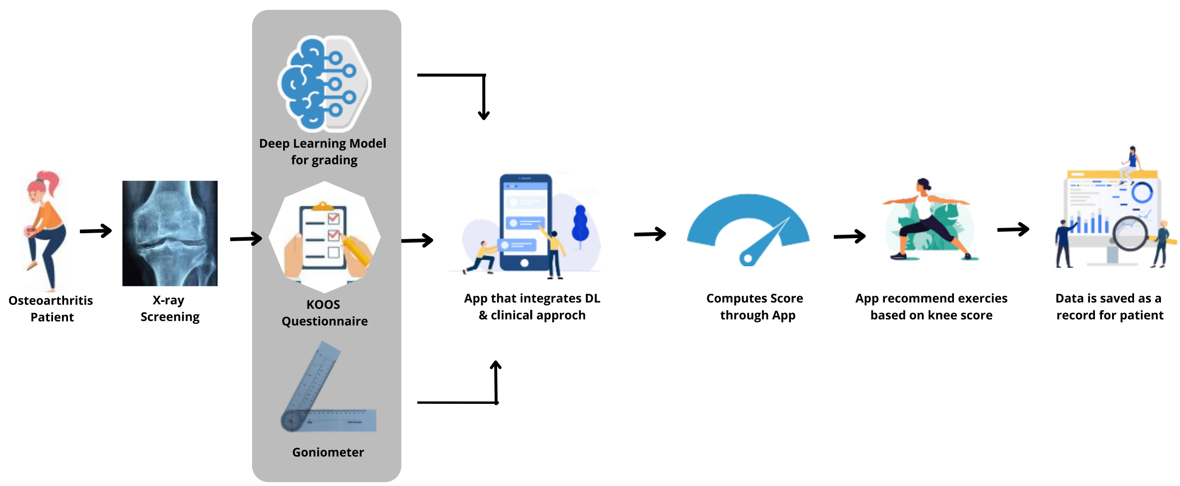


Figure 6: System Level Diagram

1.4 Structure

Following is the structure of the report ahead:

- Chapter 2 mainly deals with the explanation of Osteoarthritis, its causes, symptoms and treatments undertaken to establish grounds for developing the proposed solution.
- Chapter 3 deals with the literature review of the project, exploring related work and solutions and establishing how the project is different from existing solutions.
- Chapter 4 mainly consists of the methodology and development of the tri-weightage model adapted in this project.
- Chapter 5 deals with the experimentation and results from our deep learning models and discusses their architectures.
- Chapter 6 deals with the design and development of the software and hardware part and explains the underlying theory of operation and system integration.
- Chapter 7 deals with the market analysis along with effective and efficient deployment of the solution.
- Chapter 8 concludes the report and explores future possibilities and directions in which the project can be taken.

Chapter 2: Osteoarthritis

32.5 million people worldwide are affected by osteoarthritis and the number is increasing day by day mainly because of poor food choices resulting in obesity and other genetic factors which further contribute to these triggers.

2.1 Symptoms

Osteoarthritis is not an overnight thing it takes time to develop and slowly shows its symptoms and worsens over time. Some of the indicators that one should watch for are as follows:

Table 1: Symptoms of Osteoarthritis

Symptoms	**Details of the symptoms**
Pain	Affected joints might hurt during or after movement.
Stiffness	Joint stiffness might be most noticeable upon awakening or after being inactive.
Tenderness	Your joint might feel tender when you apply light pressure to or near it.
Loss of flexibility	You might not be able to move your joint through its full range of motion.
Grating sensation	You might feel a grating sensation when you use the joint, and you might hear popping or crackling.
Bone spurs	These extra bits of bone which feel like hard lumps can form around the affected joint.
Swelling	This might be caused be soft tissue inflammation around the joint.

Often people overlook such symptoms and gradually develop serious conditions resulting in pain and eventually knee replacement surgeries.

2.2 Causes

Firm tissue that is slippery in nature and acts as a cushion between two bones is known as Cartilage. The nearly frictionless motion of joints is made possible because of this tissue.

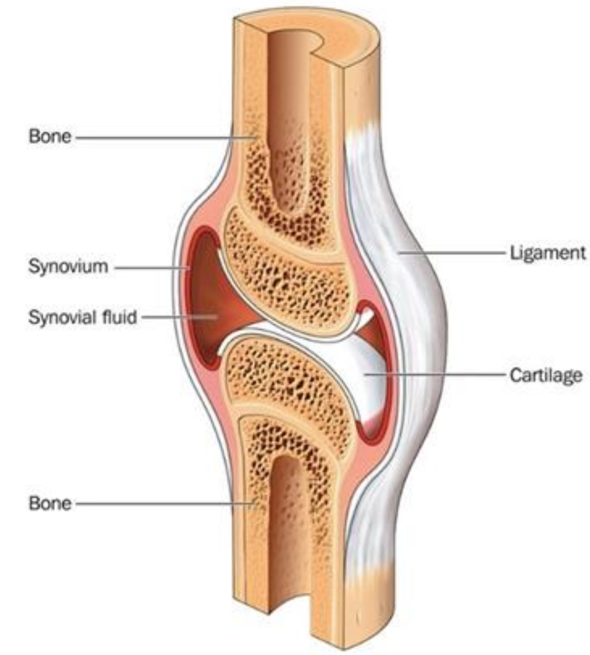


Figure 7: Cross sectional view of knee joint

When the bones rub against each other because of multiple factors it affects the joint's health eventually resulting in wear and tear of the cartilage but is not limited to cartilage only as it also affects the other components like cartilage as well resulting in extreme inflammation.

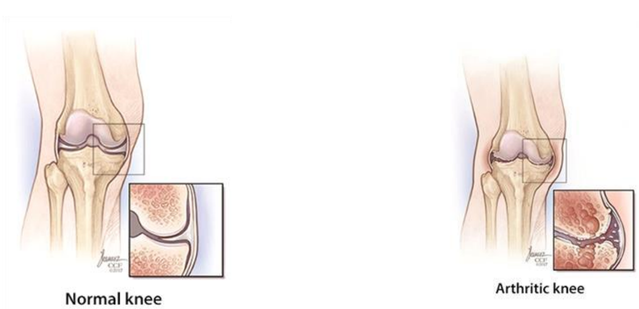


Figure 8: Normal vs Arthritic Knee

2.3 Kellgren and Lawrence Grading (KL Grading)

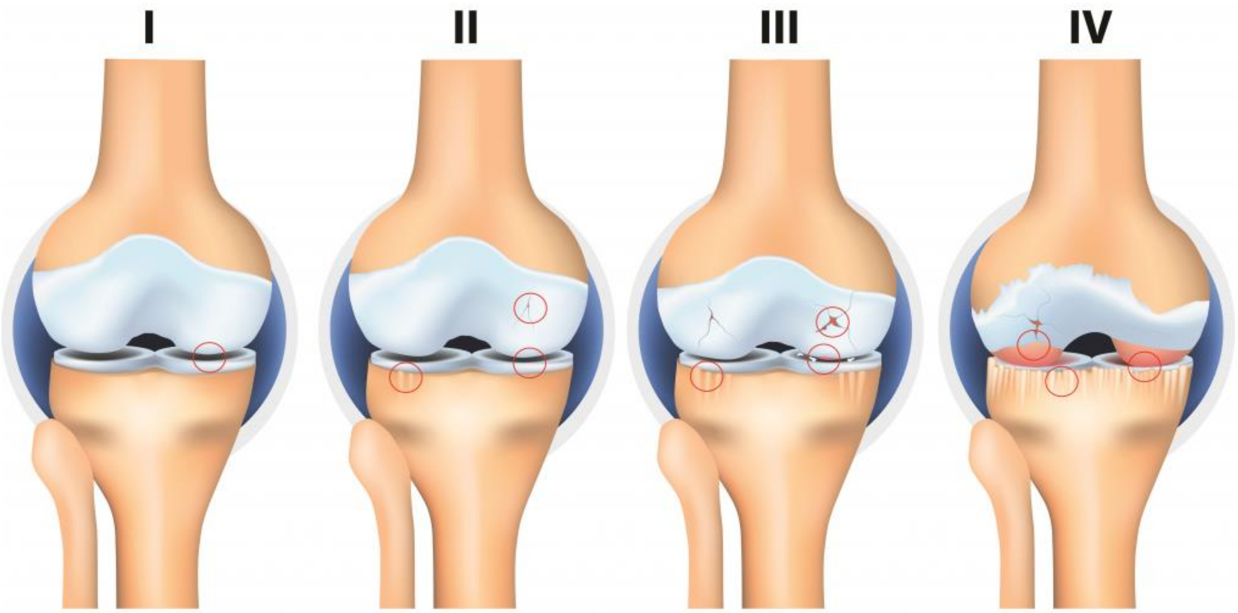
It is the most common way of grading Knee osteoarthritis and was proposed by Kellgren and Lawrence in 1957 and WHO accepted their work in 1961 as the radiological definition of OA for the purpose of epidemiological studies.

Paper graded OA at the following joints:

Table 2: Body parts and respective projections

Body Part	**Projections**
Hands	Posteroanterior
Cervical Spine	Lateral
Lumbar Spine	Facet joints only Lateral
Hips	Anteroposterior
Knees	Anteroposterior
Feet	Anteroposterior

Illustration below will be helpful in understanding these grades visually



Minimum disruption. There is already 10% cartilage loss.	Joint-space narrowing. The cartilage begins to break down. Occurrence of osteophytes.	Moderate joint-spacing reduction. Gaps in the cartilage can expand until they reach the bone.	Joint-space greatly reduced. 60% of the cartilage is already lost. Large osteophytes.

Figure 9: Illustration of Knee Grades

2.4 Complications

Dealing with a degenerative disease is not easy as it worsens over time. Chronic pain stress and stiffness of joints can make one's life miserable and can easily hamper a person from performing his/her daily tasks. Depression and sleep disturbance can result from the pain and disability of osteoarthritis which further contributes to other problems as one's circadian rhythm is disturbed.

2.5 Diagnosis

Imaging of the joint is necessary for diagnosis and for this purpose various methods and techniques are being applied the two most common types are Magnetic Resonance Imaging (MRI) and the other is X-Rays.

Figure 10: MRI and Xray image

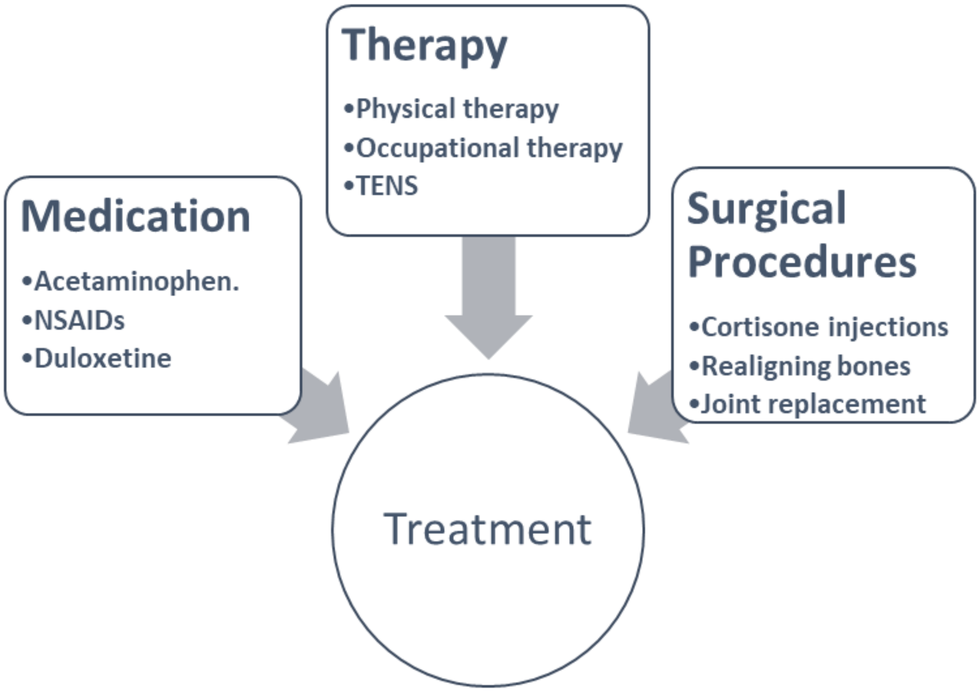
The table below compares the two techniques in terms of details, dimensions captured, visibility of cartilage, cost and availability.

Table 3: Comparison between X-Rays and MRI

	X-Rays	**MRI**
Details	Bone shape and space between joints are observed	An MRI uses radio waves and a strong magnetic field to produce detailed images of bone and soft tissues
Dimension	2D	3D (2D Slices)
Visibility of Cartilage	Cartilage doesn't show up on X-ray images, but cartilage loss is revealed by a narrowing of the space between the bones in your joint	Detailed imaging of cartilage is possible
Cost	Low as compared to MRI	High as compared to X-Rays
Availability	Commonly available	MRI facility is usually available at every good diagnostics centre. MRI isn't commonly needed to diagnose osteoarthritis but can help provide more information in complex cases.

2.6 Treatment

Osteoarthritis can't be cured, but therapies can help you feel better and move more freely. There are three types of treatments used for OA patients



Medications

The following medications is usually used for pain management:

- **Acetaminophen:** Acetaminophen can help some patients with low to moderate osteoarthritis pain.

- **Nonsteroidal anti-inflammatory drugs (NSAIDs):** Over-the-counter drugs like ibuprofen can be used for the above-mentioned purpose as well.

Therapy

- **Physical therapy:**
  A physical therapist can demonstrate you what to do to strengthen the muscles that surround your joint, develop flexibility, and relieve pain. Swimming or walking, for example, also are mild workouts that you may enjoy on your own.

- **Occupational therapy:**
  An occupational therapy could help you determine how to go about your everyday duties without straining your painful joint. If you have osteoarthritis in your knees, a shower seat can aid relieve the strain of standing.
- **Transcutaneous electrical nerve stimulation (TENS):**

A low-voltage electrical current can be of some use in these cases to manage the pain or at least defer it for some time.

Surgical and other procedures

If conservative therapy is ineffective, you may want to undergo surgeries like:

- **Cortisone injections:**
  Corticosteroid shots into your knee may help alleviate discomfort for a few weeks. Before administering medication into the joint cavity with a needle, your physician numbs the region around your knee. Since cortisone injections increase joint deterioration, the number of shots you can get per year is usually limited to three or four.
- **Realigning bones:**
  An osteotomy may be advantageous if osteoarthritis has impaired one side of your knee more than the other. In a knee osteotomy, a surgeon makes an incision through the bone up or down knee and then separates or inserts a wedge of bone. As a result, the weight of your body is shifted away from the damaged part of your knee.
- **Joint replacement:**
  Your surgery removes your defective joint surfaces and replace those with plastic and metal structures during joint replacement surgery. Inflammation and clotting are two surgical complications. Artificial joints may wear out or loosen over time, forcing replacement.

Chapter 3: Literature Review

3.1 Different Imaging Techniques

We have categorized our literature review into four parts based on the imaging modalities used in diagnosis and categorization.

- **Radiographs**
- **Magnetic Resonance Imaging**
- **Computed Tomography**
- **Ultrasonography**

3.1.1. Radiographs

We have different bone imaging techniques available, but conventional X-rays are still widely used because of their availability and low costs [13]. Rather than adjacent tissues, which are more apparent features of Osteoarthritis, radiographs can offer us a clearer bone structure and Osteoarthritis features such as osteophytes, Joint Space Width narrowing, and cysts. These characteristics can help us in early detection and the management of the symptoms [14], [15]. However, they are limited to detecting minute changes in the structure. However, we may have to include other imaging techniques or tests to conclude the diagnosis [16].

Figure 11: Radiograph Image

- Evolution Criteria:

Taking measurements and then interpreting those results and the semi-quantitative grading systems provide us with certain difficulties. OARSI Atlas provides certain features and examples for particular grades instead of assigning global scoring [17]. And acts as a substitute for KL grading. It scores the Joint space between Tibia and femur bone separately and deals with the osteophytes separately. Each knee compartment is graded on a 0- 3 scale separately. Given below is the brief summary of each grade [18], [19], [20].

Table 4: OARSI grading for different joint conditions

Grade	Condition
0	Normal Joint
1	Mild Problem
2	Moderate Presence
3	Severe Joint Condition

- Quantification Workflows:

In the literature, there are several ways to extract features. Compute kinematic factors and use them as features, which are then categorized using support vector machines (SVMs) with a 97.4 % accuracy [21]. Additionally, Radial Basis Function networks, random forest and Naïve Bayes were used to achieve comparable accuracy [22] [23] using the gray-level co-occurrence matrix with Gabor kernel, yielding a 53.34 % accuracy. However, only 4 % of the radiographs were categorized accurately as KL grade 2 [24]. The joint region was selected as the ROI, and the features were manually extracted; then, a K-Nearest classifier was applied at the end.

3.1.2. Magnetic Resonance Imaging

Provides high Image resolution. The patient is also not exposed to the high ionizing radiation and can provide 3D Images. The structure of the cartilage and the biochemical composition of the joint can be captured using MRI.

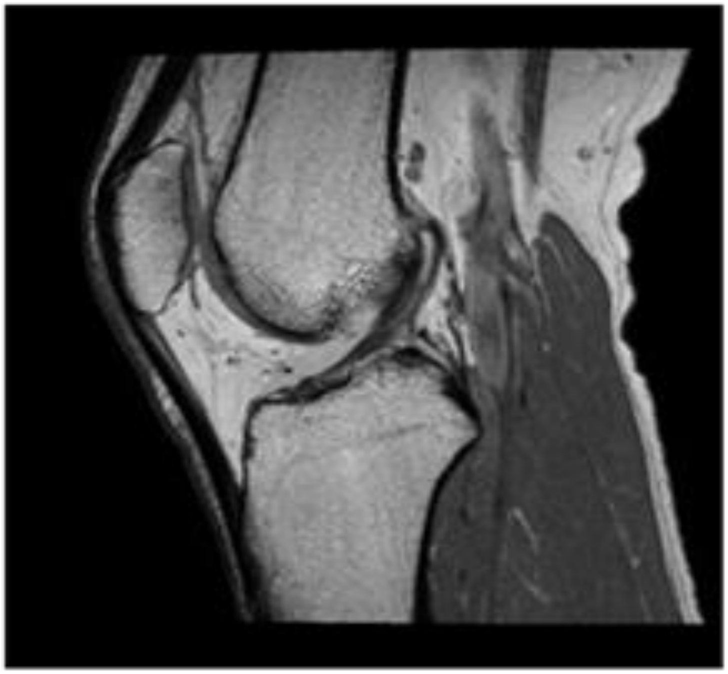


Figure 12: Magnetic Resonance Image (MRI)

- Evaluation Criteria:

WORMS (Whole-Organ Magnetic Resonance Imaging Score), BLOKS (Boston Leeds Osteoarthritis Knee Score), KOSS (Knee Osteoarthritis Scoring System), KIMRISS (Knee Inflammation MRI Scoring System) and MOAKS (MRI Osteoarthritis Knee Score) are some well-known MRI scoring systems, with BLOKS and WORMS being the most widely used [17], [25]. Like the OARSI atlas, other assessment methodologies focus on a wide range of OA-related physical deformities in cartilage, soft tissue, and bones in the knee and different sub-regions [26].

- Quantification Workflows:

MRI is capable of providing images of soft tissues. However, contrast and light conditions can cause incorrect edge detection [27]. For this reason, the radiographic segmentation and edge detection approach still lead. Then the next steps that follow are masking and applying a canny edge detector for edge detection through finding image gradients and their local maxima will provide us with the required fields [28], [29]. ii) Finding the ROI. MRI segmentation based on classification is used widely, where each voxel-A 3D equivalent of a pixel- is classified into two classes. It can be thought of as slicing into three sets of 2D images generated from 3D MRIs. These images are then labeled for the CNN classifier based on the presence or absence of each landmark [30]. Images are then divided into a set of cells. Intensities of those cells are then used as features for the Gaussian Mixture Model. These classified cells are then grouped by heuristic search iteratively through a Genetic Algorithm. K-means controls the number of clusters in case of creating many segments, just like the watershed algorithm [31].

3.1.3 Computed Tomography

Radiographs and MRIs are unclear and contraindicated for hip Osteoarthritis, but CT scans can detect these abnormalities [13]. As the image quality of the CT scans is relatively better than the other methods, it serves as a good method for bone abnormalities and soft tissue classification [13]. However, getting access to a credible database is still a problem.

Figure 13: CT scan

3.1.4 Ultrasonography

As MRI is a high-cost option, it leads us to the ultrasound as a relatively cheaper imaging tool for quantitative assessments of different anatomical structures and their properties, as discussed earlier. But ultrasound cannot visualize subchondral changes [17]. These methods have been deployed massively, but old techniques like different scoring methods are still preferred [17].

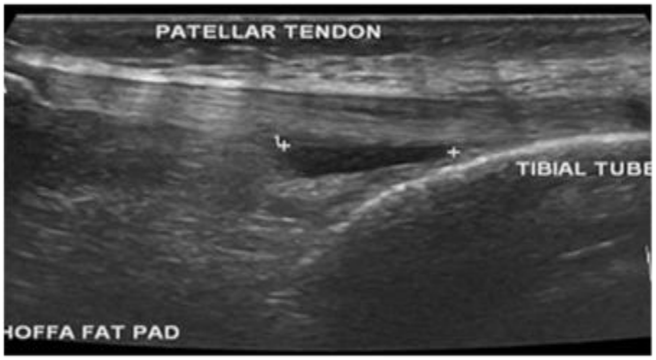


Figure 14: Ultrasonographic image

Table 5: Dimensions of different techniques

Technique	**Dimensionality**	**Cost**
Radiographs	2D	Low
Magnetic Resonance Imaging	3D	High
Computed Tomography	3D	High
Ultrasonography	3D	Low

Chapter 4: Methodology

4.1 Clinical Diagnosis

Osteoarthritis (OA) is the most common arthropathy, that affects most of the joints including fingers, hips and knees, manifesting itself in a variety of ways. OA symptoms include coarse crepitus, sourness in joint, restricted range of motion for the joint and most importantly bone growth. Severe OA causes muscle loss and joint deformities. Periarticular diseases usually accompany osteoarthritis that eventually increases the intensity of pain. Mild to moderate outpourings are common around the knees, but only slight irritation is present. The diagnosis of OA can be made without the use of radiography or laboratory testing in those who are in the at-risk age range and have specific symptoms.

4.2 KOOS Questionnaire

It is a questionnaire designed to assess short and long-term patient-relevant based on pain, symptoms, activities of daily living, sport and recreation function, and quality of life. It can be self-administered to calculate a final score out of 100.

It is widely used because of its user-friendly nature and it takes around 10 minutes to calculate the final score.

- Scoring instructions: All five dimensions are scored individually using Likert scale and all items have 5 possible answer to choose from ranging between 0 (No problems) to 4 (Extreme problems) after scoring all five dimensions a sum total of all the individual scores is calculated to display a final result.

- Interpretation of scores: Scores are represented on a 0–100 scale, with 0 % representing extreme knee problems and 100 % representing no knee problems as common in orthopedic scales and generic measures.

$$KOOS = \sum_{i=1}^{9} P_i + \sum_{i=1}^{6} S_{yi} + \sum_{i=1}^{17} A_i + \sum_{i=1}^{5} S_{pi} + \sum_{i=1}^{4} Q_i \qquad (1)$$

P_i represents the sum total of all “Pain points” in the KOOS, similarly S_{yi}, A_i, Q_i and S_{pi} represent the sum total of symptoms, activities, sports/recreational and Quality of life related questions. In the original text we have 9,6,17,5 and 4 questions for each point respectively as illustrated in the equation 1 above.

The summary of all questions and their respective paint points is illustrated below:

- **Pain:** (P_i)

Table 6: KOOS Pain Questionnaire

P1 How often is your knee painful?	☐ Never	☐ Monthly	☐ Weekly	☐ Daily	☐ Always
What degree of pain have you experienced the last week when…?					
P2 Twisting/pivoting on your knee	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P3 Straightening knee fully	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P4 Bending knee fully	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P5 Walking on flat surface	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P6 Going up or down stairs	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P7 At night while in bed	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P8 Sitting or lying	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
P9 Standing upright	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme

- **Symptoms:** (S_{yi})

Table 7: KOOS Symptoms Questionnaire

Sy1 How severe is your knee stiffness after first wakening in the morning?	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sy2 How severe is your knee stiffness after sitting, lying, or resting later in the day?	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sy3 Do you have swelling in your knee?	☐ Never	☐ Rarely	☐ Sometimes	☐ Often	☐ Always
Sy4 Do you feel grinding, hear clicking or any other type of noise when your knee moves?	☐ Never	☐ Rarely	☐ Sometimes	☐ Often	☐ Always
Sy5 Does your knee catch or hang up when moving?	☐ Never	☐ Rarely	☐ Sometimes	☐ Often	☐ Always
Sy6 Can you straighten your knee fully?	☐ Always	☐ Often	☐ Sometimes	☐ Rarely	☐ Never
Sy7 Can you bend your knee fully?	☐ Always	☐ Often	☐ Sometimes	☐ Rarely	☐ Never

- **Activities of daily living:** (A_i)

What difficulty have you experienced the last week…?

Table 8: KOOS Activity of daily living Questionnaire

A1 Descending	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A2 Ascending stairs	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A3 Rising from sitting	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A4 Standing	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A5 Bending to floor/picking up an object	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A6 Walking on flat surface	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A7 Getting in/out of car	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A8 Going shopping	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A9 Putting on socks/stockings	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A10 Rising from bed	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A11 Taking off socks/stockings	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A12 Lying in bed (turning over, maintaining knee position)	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A13 Getting in/out of bath	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A14 Sitting	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A15 Getting on/off toilet	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A16 Heavy domestic duties (shovelling, scrubbing floors, etc)	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
A17 Light domestic duties (cooking, dusting, etc)	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme

- **Sports and recreation function:** (S_{pi})

What difficulty have you experienced the last week…?

Table 9: KOOS Sports and recreation function Questionnaire

Sp1 Squatting	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sp2 Running	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sp3 Jumping	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sp4 Turning/twisting on your injured knee	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Sp5 Kneeling	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme

- **<u>Knee-related quality of life:</u> (Q_i)**

What difficulty have you experienced the last week…?

Table 10: KOOS- Knee related quality of life Questionnaire

Q1 How often are you aware of your knee problems?	☐ Never	☐ Monthly	☐ Weekly	☐ Daily	☐ Always
Q2 Have you modified your lifestyle to avoid potentially damaging activities to your knee?	☐ Not at all	☐ Mildly	☐ Moderately	☐ Severely	☐ Totally
Q3 How troubled are you with lack of confidence in your knee?	☐ Not at all	☐ Mildly	☐ Moderately	☐ Severely	☐ Totally
Q4 In general, how much difficulty do you have with your knee?	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme

4.3 Flexion Angle

Extent to which you can bend your knee is known as the knee flexion angle. It can be helpful for finding the range of motion of knee joint and can be easily measured using goniometer. We will explain the working of goniometer and a proposed app for simulation of goniometer for this problem.

Table 11: Flexion Angles

Condition	Angles
Hyper Extended	-5 degrees
Fully Extended	0 degrees
Under Extended	5 degrees

4.4 Tri-Weightage classification Model

When rapid and robust image preprocessing is required on X-Ray images, Cellular Neural Network (CNN)-based method is a suitable choice. To date, several uses of CNNs in biological imaging have been proposed [10]. Deep learning (DL) technology opened the path for recent developments in the field of computer vision, resulting in an increase in automated medical diagnostics and the use of computers for decision-making in medical domain [11]. Generally, the research trend related to classification of different diseases and abnormalities focuses on achieving high accuracy and also the reason behind the classification should also be clear so that it can be used as a reliable method for diagnosis and medical practitioners can fully trust the systems. Traditional Machine Learning focuses on extraction of features before implementation of any algorithm whereas deep learning focuses on the data and tries to extract features from the data on its own [12]. Deep learning model enhances the accuracy as it does not require us to extract features before formulating a solution however it should be combined with some other controlling parameters which the doctor or patients will provide according to their conditions

Chapter 5: Experimentation and Results

5.1 Dataset

Bilateral PA fixed flexion knee X-ray images were used for the experiments and analysis in this study. The dataset is from the Osteoarthritis Initiative (OAI) at the University of California, San Francisco, and is the standard dataset used in knee osteoarthritis studies.

5.1.1 Labels of dataset (Kellgren and Lawrence Grades):

To classify the knee OA X-ray pictures, this study used Kellgren and Lawrence (KL) grades as the ground truth. In radiographs, the KL grading system is still regarded the gold standard for determining the severity of knee osteoarthritis. It uses five grades to indicate radiographic knee OA severity. 'Grade 0' represents normal, 'Grade 1' doubtful, 'Grade 2' minimal, 'Grade 3' moderate, and 'Grade 4' represents severe. The figure shows the KL grading system.

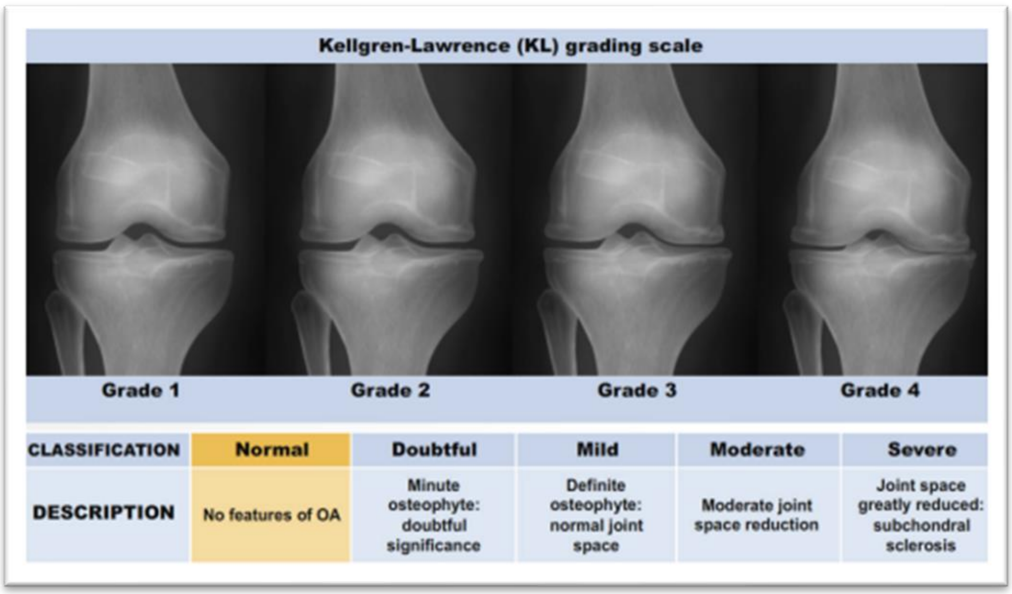


Figure 15: KL Grading System

Eight thousand two hundred and sixty (8260) radiographs were collected from the Kaggle dataset organized from OAI [9]. The distribution as per the KL grades is as follows: Grade 0 - 3433, Grade 1 - 1589, Grade 2 - 2353, Grade 3 - 1222, and Grade 4 - 295. Dataset had images for both left and right knees, with each image having a size of 224 x 224. Each of these cases was already graded by radiologists involved in developing the OAI dataset.

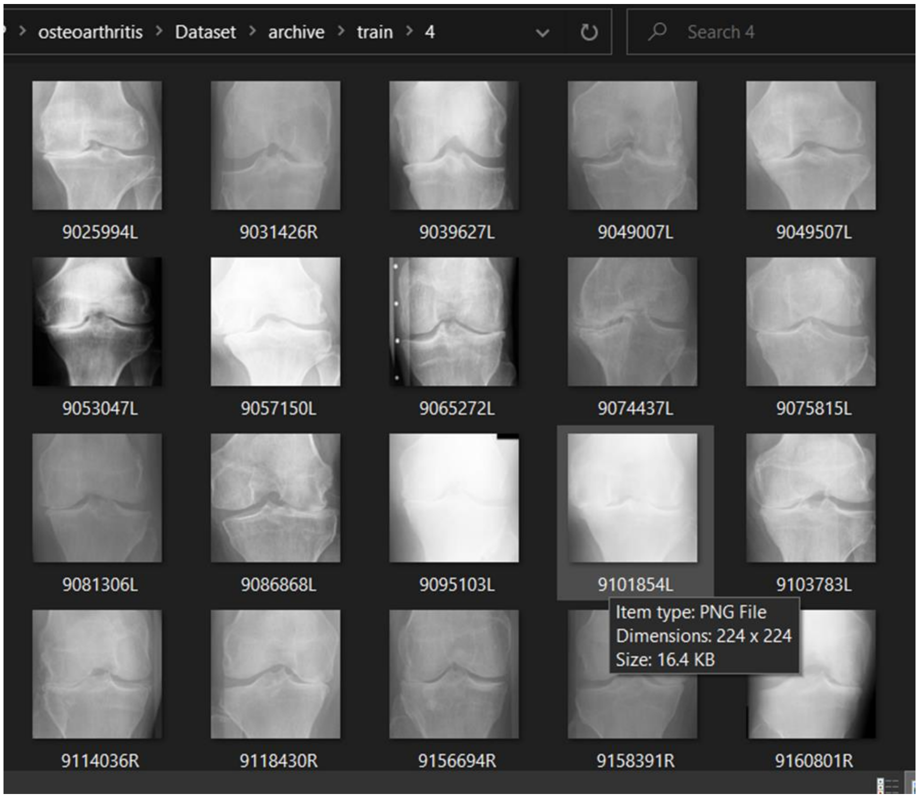


Figure 16: OAI Dataset

5.1.2 Data Augmentation:

As the distribution of images among different classes is not balanced thus, we used the data augmentation technique using Roboflow.

Roboflow is a developer tool for better data preprocessing and model training techniques in computer vision. Roboflow offers consumers with access to public datasets as well as the ability to submit their own custom data. Roboflow supports a variety of different annotation formats. Image orientations, resizing, contrasting, and data augmentations are all aspects in the data preprocessing process.

Data augmentation is a series of techniques for producing additional data points from current data in order to increase the amount of data available artificially. This includes making minor changes to data or using deep learning models to generate new data points. It is helpful to improve the performance and outcomes of machine learning models by forming new and different examples to train datasets. If the dataset in a machine learning model is rich and sufficient, the model performs better and more accurately.

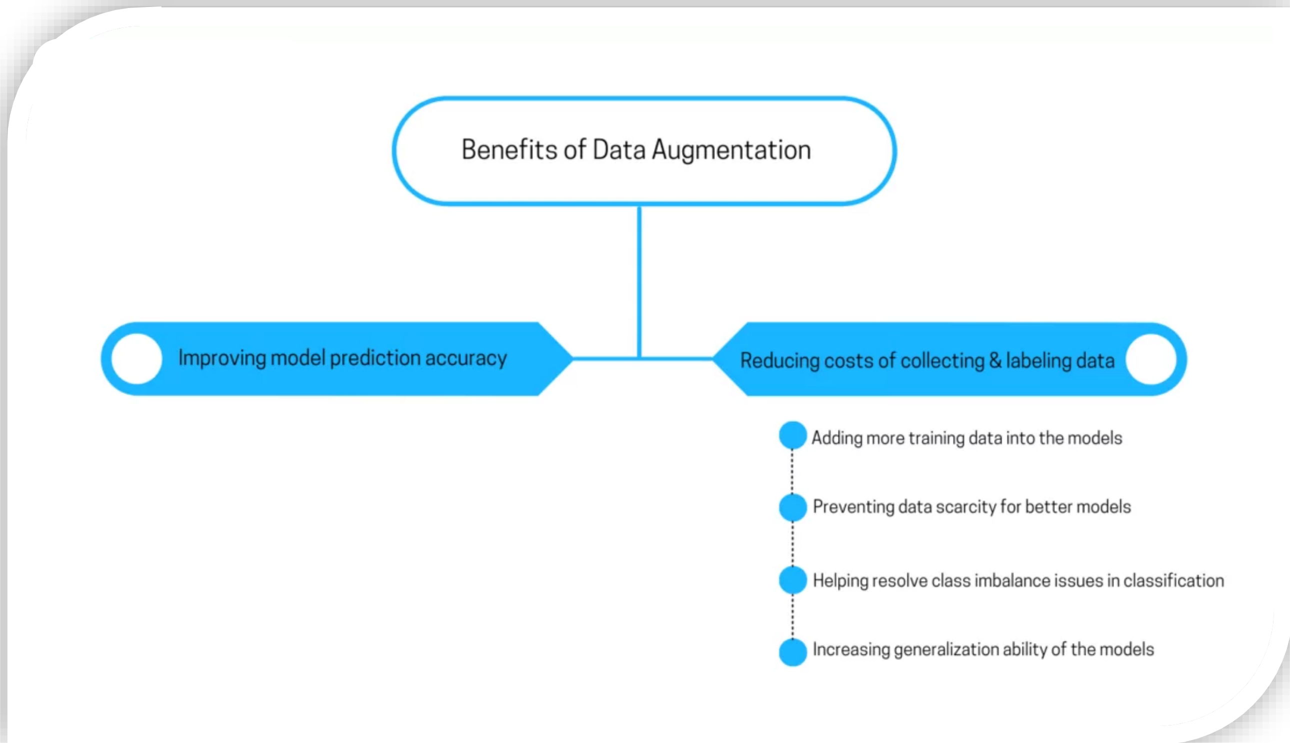


Figure 17: Benefits of Data Augmentation

Image augmentation techniques like Rotation, Flipping and Contrast were applied to the OAI dataset of radiograph images. The rotation was done on both sides at an angle of 45 degrees, flipped by an angle of 180 degrees. To overcome the imbalance of data in KL scores of 3 and 4 class, a total of 4000 images were augmented for training and testing. Data was divided with an 80/20 split resulting in 2000 training images per grading class and 500 testing images per grading class. In order to ensure the performance and adaptability of the model, the training/testing split was made such that images in testing and training were different, and no repetition of images was done.

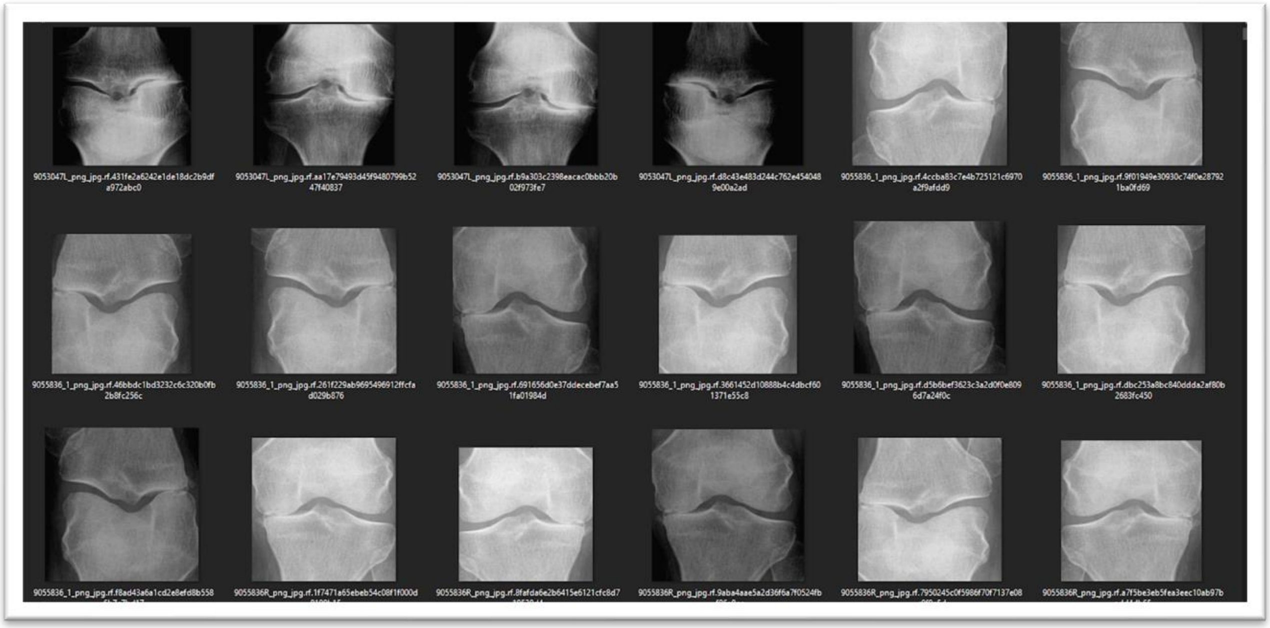


Figure 18: Augmented Dataset

5.2 Experiments:

We used different models with different variations of architectures to make the grading based on their performances with the validation dataset. We used various models to test which model best fits our requirement of grading these knee X-Ray images.
Deep Learning follows a hierarchical approach to conduct nonlinear transformations. Learning can be applied to a Convolutional Neural Network (CNN) that has a deep architecture in a feed-forward fashion. CNN's layers can see the features and show a lot of diversity. The deep convolutional network is tested in the forward direction, and all layers are differentiated during this step. Deep CNN's prominent characteristic is that it searches for every possible match between images.

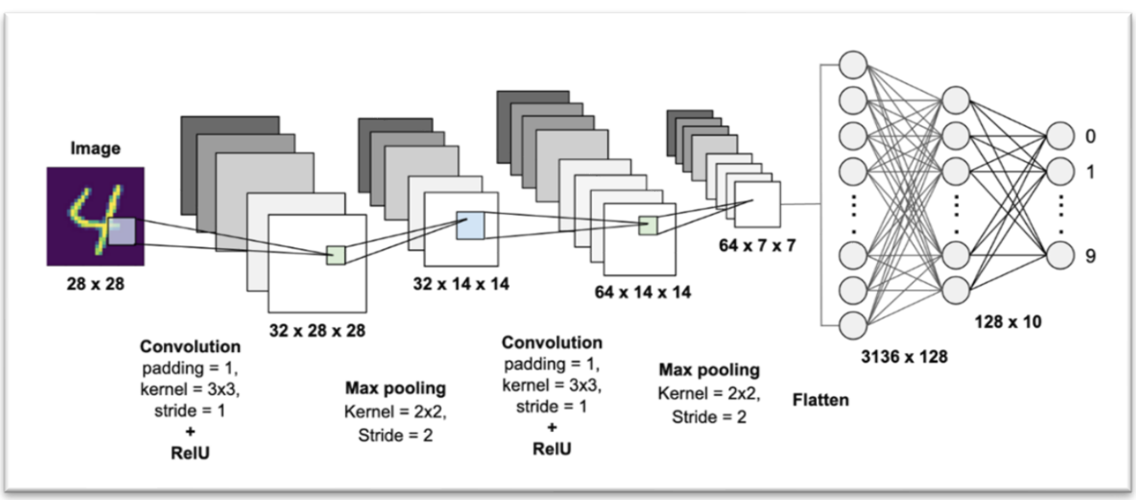


Figure 19: CNN model Architecture

5.2.1 MobNet V2:

Starting with the first model, MobNetV2, a CNN architecture that usually performs well on mobile devices. Residual connections are between the bottleneck layers, and the intermediate expansion layer uses depth wise convolutions, which are lightweight to filter out features as a source of non-linearity [32]. MobileNetV2 has a size of 14 Mb with 3.5M parameters and a Depth of 105. Applying this model to our preprocessed dataset achieved an accuracy of 0.25233, which did not provide promising results. This model performs best with mobile applications because of its lightweight.

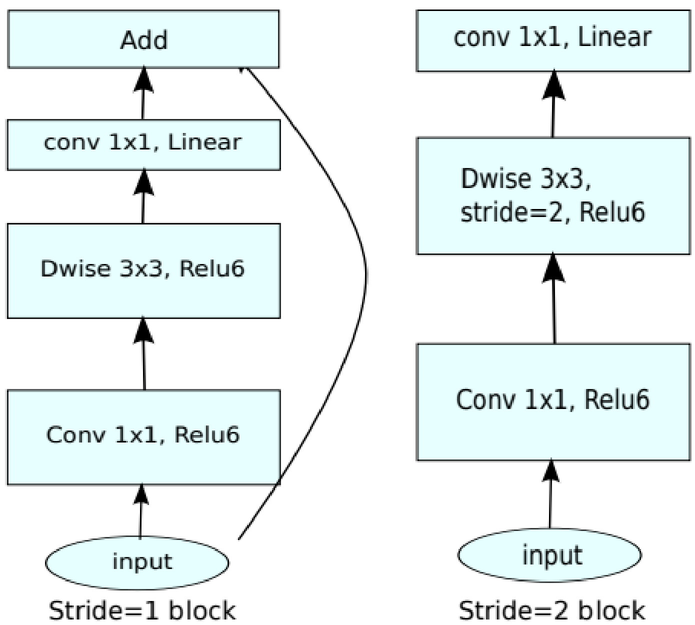


Figure 20: MobnetV2 Architecture

5.2.2 EfficentNets:

Next, we worked on Efficient Nets. The EfficientNet is, in fact, a family of models defined on the baseline network described in the figure below. The Mobile Inverted Bottleneck Conv (MBconv) Block is its key component. This model uses a multi-objective neural architecture search that optimizes accuracy and floating-point operations [33]. It tries to provide better results by horizontal and vertical expansion and taking in High-resolution images.

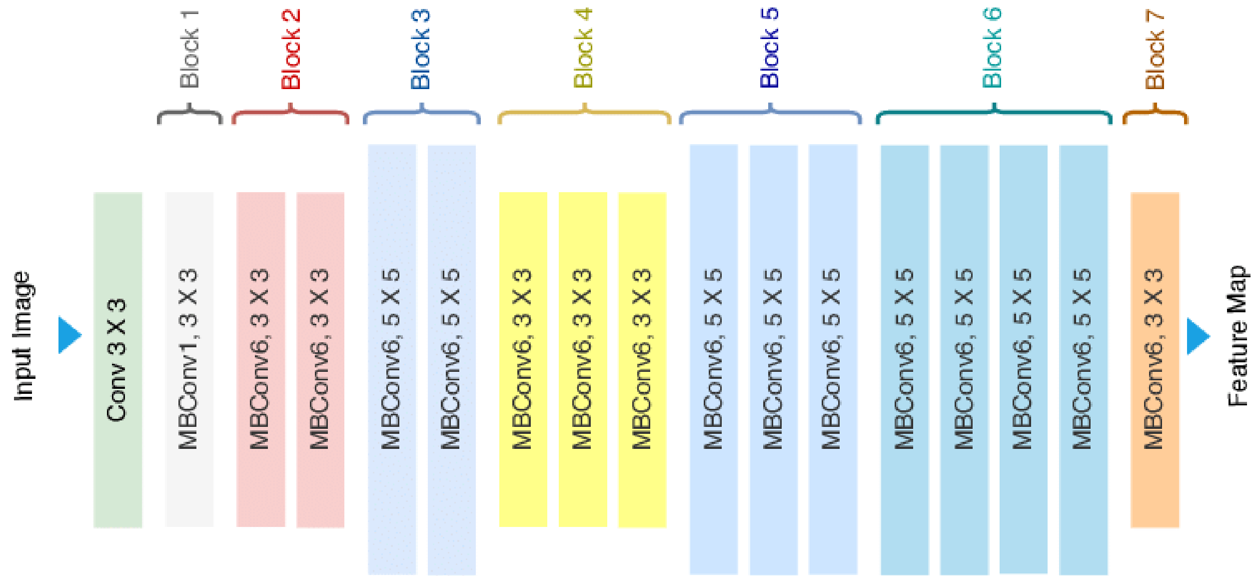


Figure 21: EfficientNet baseline network: B0 architecture

5.2.3 ResNet 152 V2:

The next model we used to compute the results for grading our radiographic images was ResNet152V2 [34]. Residual networks were proposed as a family of multiple deep neural networks with similar structures but different depths. By using residual learning units, we can alleviate the degradation of deep neural networks [34]. They are quite popular because of the introduction of skip connection which skips a few layers and can connect directly to the output layer [34]. The RestNet152V2 model has a model size of 232 MBs, 60.4M parameters and a depth of 307, which is less than the depth of ResNet152. The main merit of this unit is that it has produced better classification accuracy that is 0.89297 without increasing the complexity of the model compared to the other ResNet family.

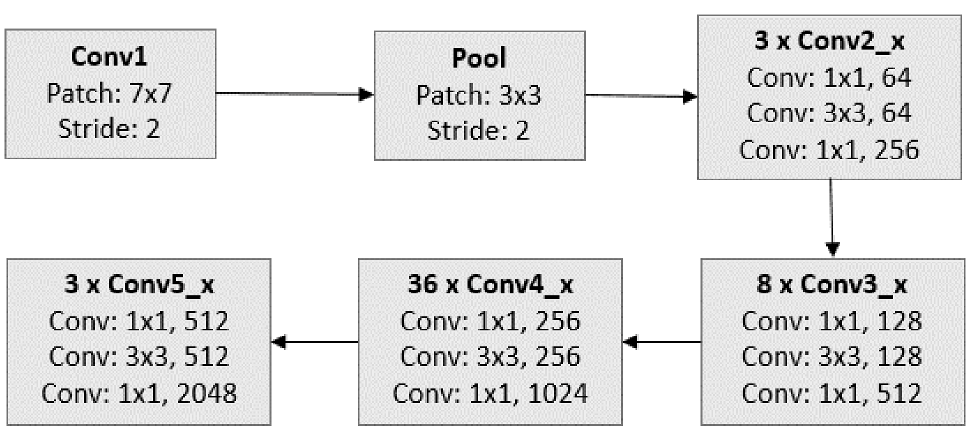


Figure 22: The basic architecture of Resnet152

5.2.4 Inception-ResNet V2:

Lastly, the model we used for grading our dataset was the Inception-ResNetV2 model. Both can provide good results at a relatively low computational cost [35]. The network is 164 layers deep. The network has an image input size of 299 x 299, and the output is a list of estimated class probabilities. Looking towards the dimensions of this model, it has a size of 215 MBs, has around 55.9M parameters, and has a depth of 449. Using Inception-ResNetV2 has proved to be one of the best models for our dataset, as it has achieved an accuracy of 0.89297. Working with multiple algorithms has resulted in
different outputs giving a clear view of how the model's architecture affects the performance and cost. A model that provides better accuracy without increasing computational complexity, which increases the cost of that model, is considered the best solution to a problem. It is also that a model that works best with one type of data might not be as efficient with a different dataset under different circumstances.

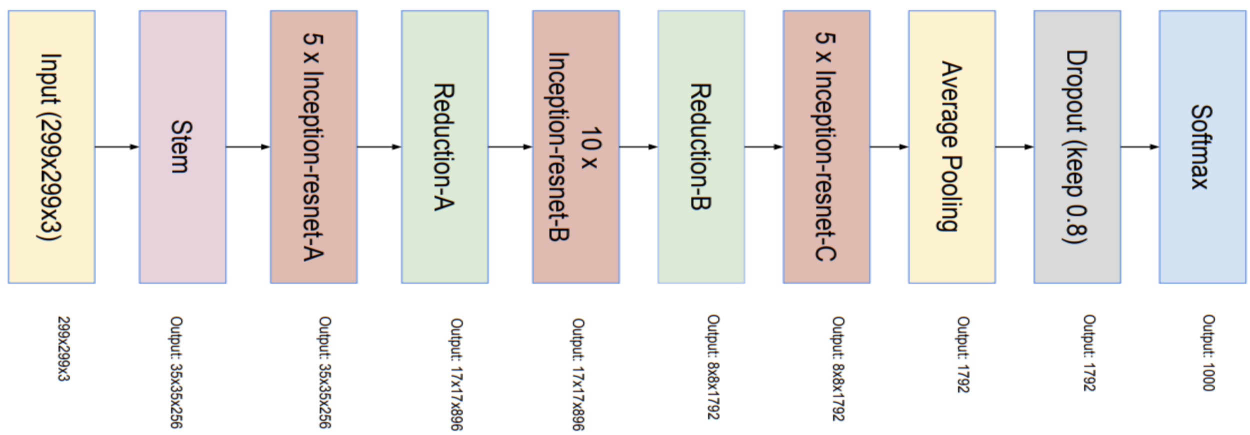


Figure 23: Inception ResNet V2 Architecture

5.3 Results:

Following results were obtained on applying different CNN models on KL graded dataset after augmentation.

Table 12: Deep Learning model results

Model	Size (MB)	Parameters	Depth	Accuracy
ResNet152V2	232	60.4M	307	0.89297
MobNet V2	14	3.5M	105	0.25233
EfficentNetB0	29	5.3M	132	0.64233
EfficentNetB4	75	19.5M	258	0.67232
InceptionResNetV2	215	55.9M	449	0.89296

Chapter 6: OSTEO-DOC AI BASED SOLUTION FOR OSTEOARTHRITIS

6.1 Mobile Application

The mobile application allows the users to harness all the research work in form of a software deliverable. The various features of the application and use cases are described below:

6.1.1 Login Screen

The login screen is the first screen which is showed when the application is started. It prompts the user to either sign-in with if the person is an existing user or new to the platform.

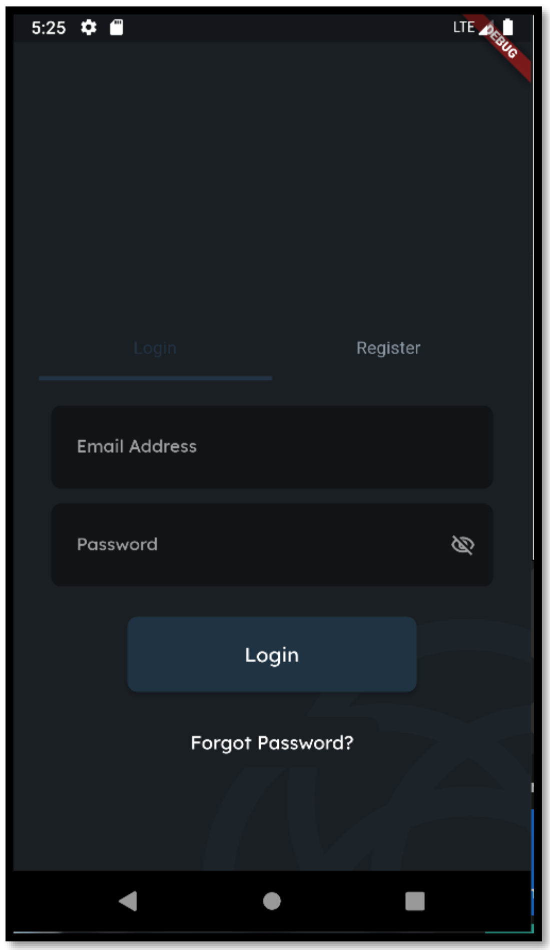


Figure 24: Mobile app Login screen

6.1.2 Home Screen

The patient home screen is where a user who is a patient is taken after sign in. Being the first screen that a patient sees upon sign in it is visually pleasing and contains the necessary information that is required quickly such as the upcoming appointments with the doctor if any.

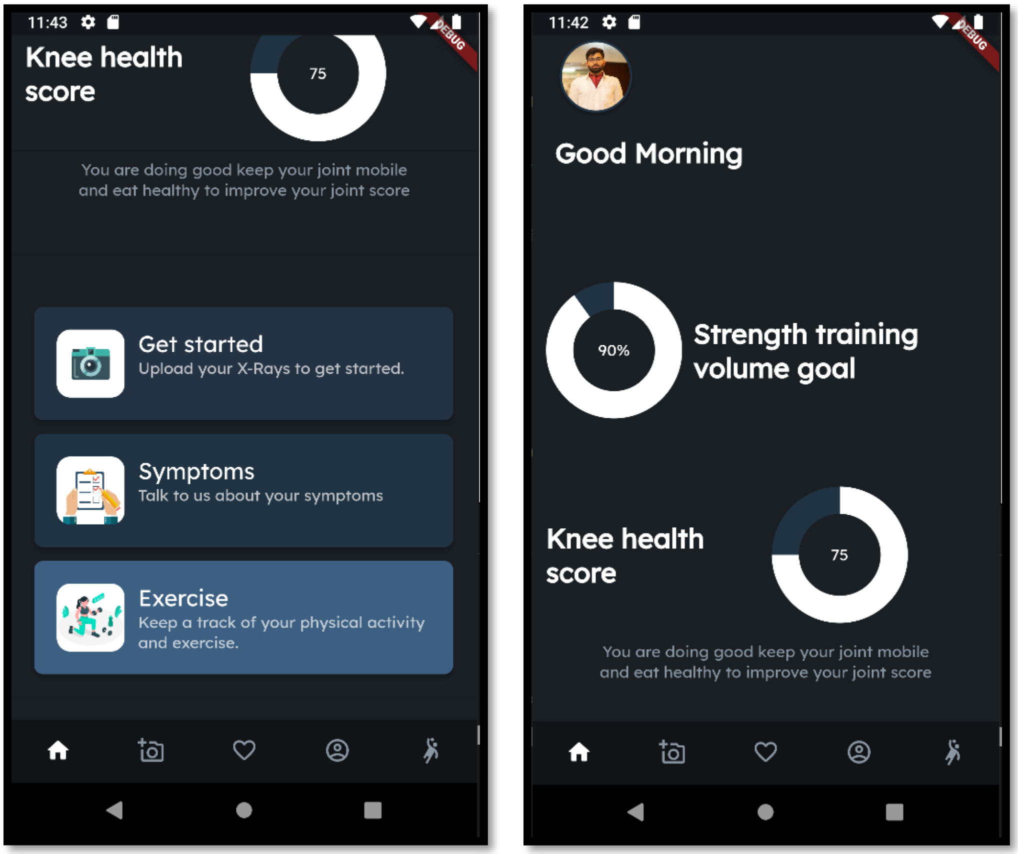


Figure 25: Mobile a home screen

6.1.3 Patient Profile

The patient profile screen shows the patients personal information which is taken at the time of registration such as date of birth, name, etc. It also shows weekly progress reports and past appointments information.

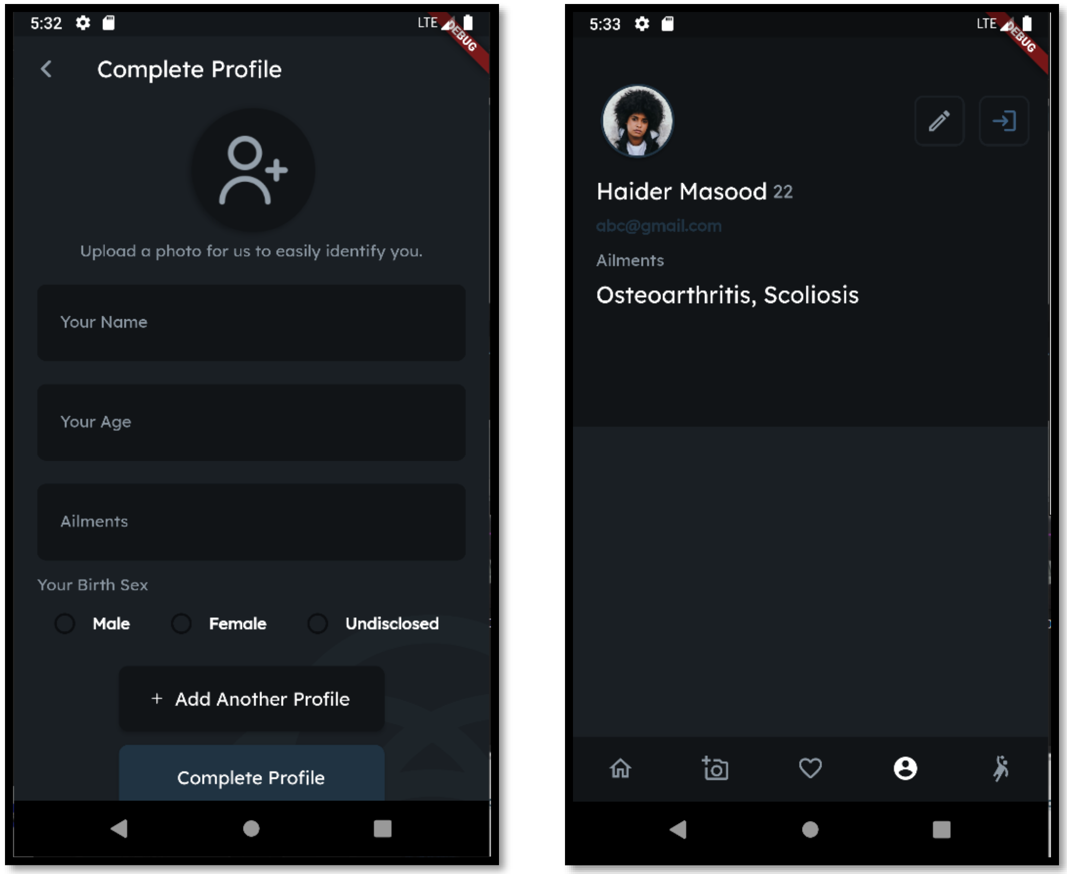


Figure 26: Mobile app profile screen

6.1.4 X-Ray Classification

X-Ray are classified every time using a .tflite model and the classifier code is as below

```
class Classifier {
  final double confidence;
  final int index;
  final String label;

  Classifier({
    this.confidence,
    this.index,
    this.label,
  });

  // factory Classifier.fromJson(Map<String, dynamic> json) => Classifier(
  Classifier.fromJson(Map<String, dynamic> json)
      : confidence = json["confidence"].toDouble(),
        index = json["index"] as int,
```

```
    label = json["label"] as String;

  static List<Classifier> fromJsonList(List<dynamic> jsonList) => jsonList
      ?.map((e) => Classifier.fromJson(Map<String, dynamic>.from(e)))
      .toList();

  @override
  String toString() =>
      '{confidence: $confidence, index: $index, label: $label}';
}
```

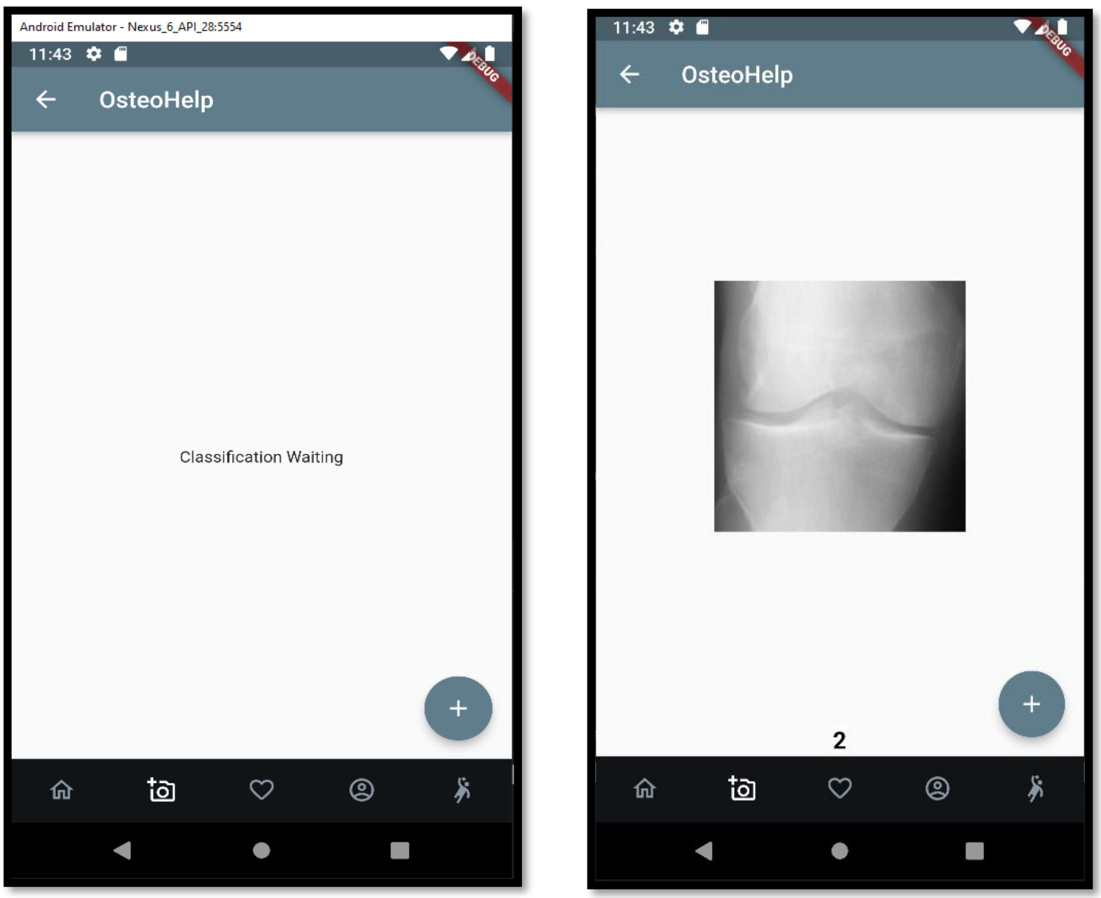


Figure 27: Mobile app classification screen

6.1.5 Exercise Logs

Exercise logs of the last 7 days are maintained locally and the user has the choice to add/edit logs of the last 24 hours.

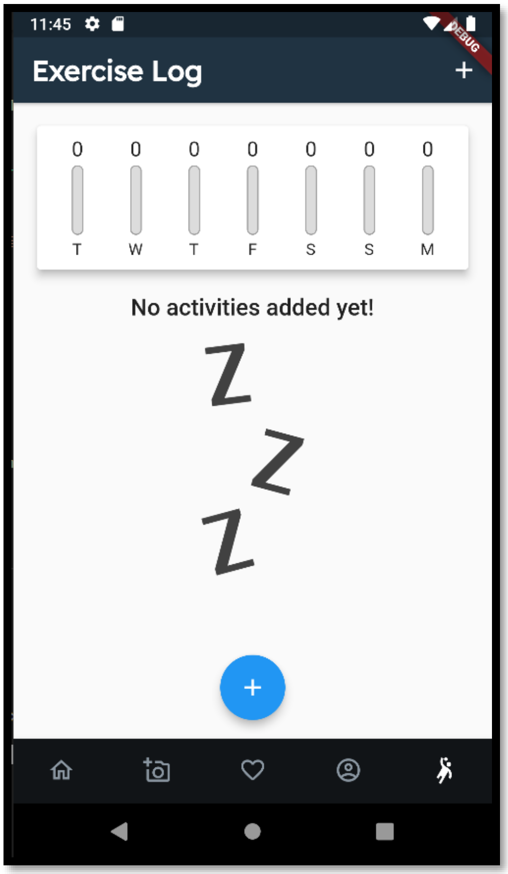


Figure 28: Mobile app Exercise log screen

6.1.6 KOOS Questionnaire

The user is required to fill the KOOS Form every week to get a Final KOOS score which in turn will be utilized to compute the final knee health score.

The following equation is used to compute the final score or output:

$$KOOS = \sum_{i=1}^{9} P_i + \sum_{i=1}^{6} S_{yi} + \sum_{i=1}^{17} A_i + \sum_{i=1}^{5} S_{pi} + \sum_{i=1}^{4} Q_i \tag{1}$$

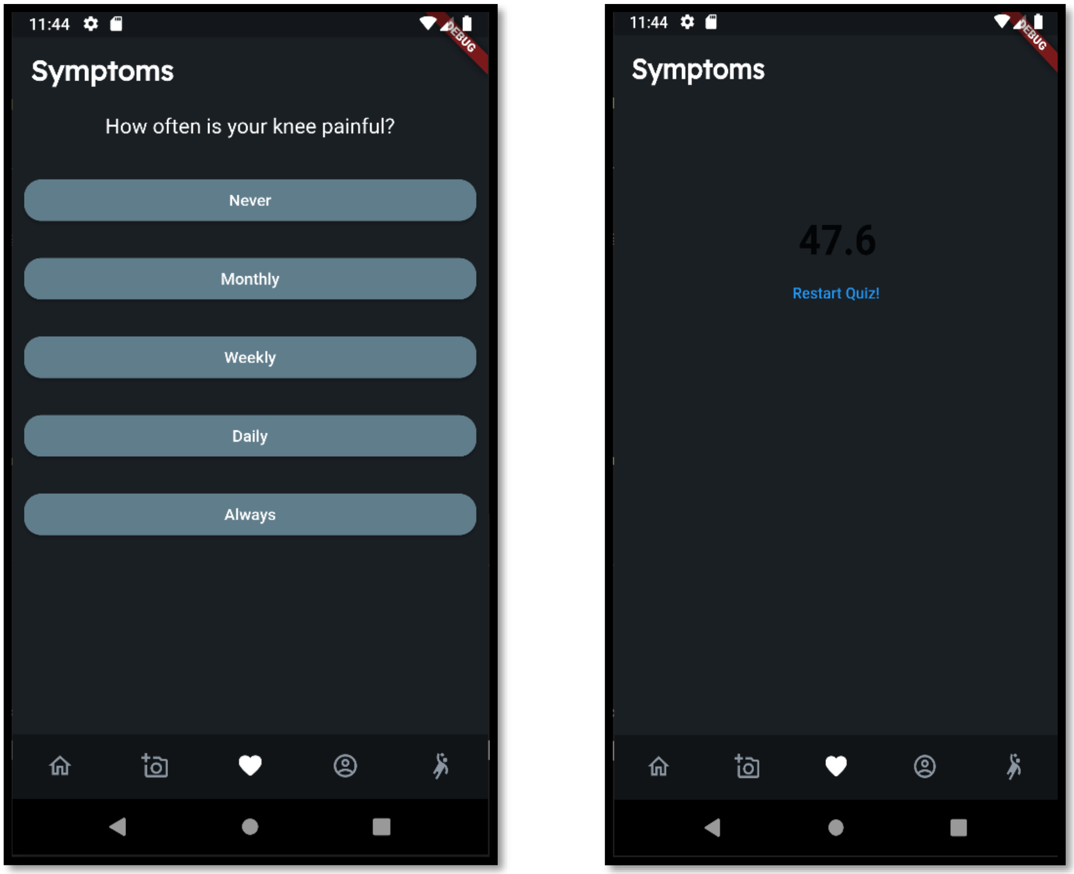


Figure 29: Questionnaire Screen

6.2 Virtual Goniometer

First, we went with the approach of making a virtual goniometer and implement the final model on Nvidia Jetson nano and used the media pipe library to calculate the Joint angle of the joint visible in live camera feed.

Given below is an approximate cost breakdown of this solution.

Table 13: Virtual Goniometer Cost

Component	Price	Accumulated Price
 Nvidia Jetson Nano	17,000 Rs	17,000 Rs
 Webcam	2,000 Rs	19,000 Rs
 3D Printed Casing	4,000 Rs	23,000 Rs

Attached below is the screenshot of the feed of the webcam.

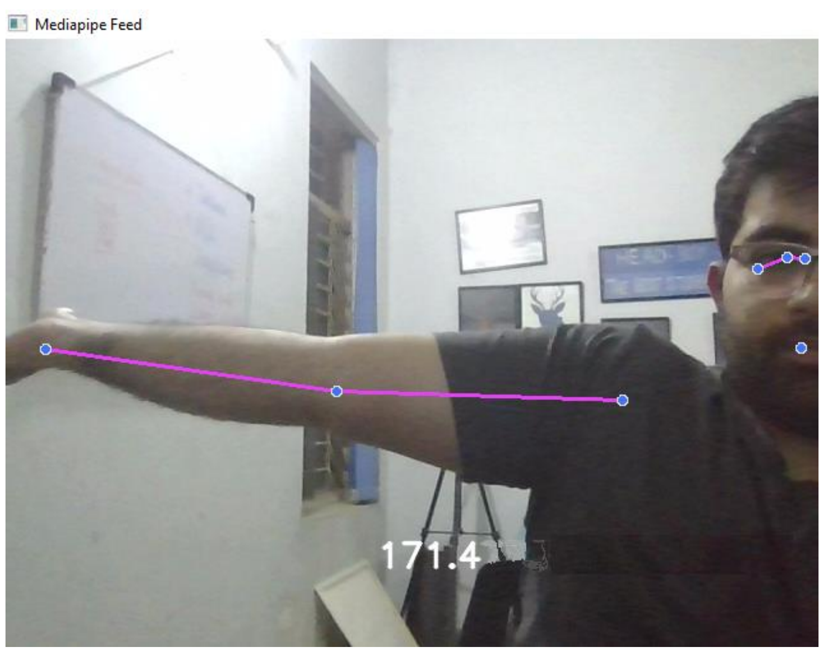


Figure 30: Virtual Goniometer Angle measuremen

6.3 Hardware Goniometer

After successful implementation of the virtual goniometer, we were supposed to provide a solution for doctors based on Nvidia Jetson nano and the price of one Unit was above 20,000 Rupees.

After doing some research we found two alternatives with the following pros and cons

And went on exploring servo motors as it was the cheapest solution possible if somehow we are able to access the angle value of the servo arm.

Table 14: Comparison between Flex sensor and Servo motor

Alternatives	Pros	Cons
Flex sensor	Can detect even the slightest change in flexion and are built for this specific purpose	• Reading can be changed even if the joint is twisted as the sensor is quite sensitive • Costly • Accuracy
Servo Motors	• Can measure the angle with a high accuracy. • Can be fixed in a 3D printed Only allows sideways movement	• Cannot read the angle from the servo directly • PWM signal does not allow movement of servo arm.

6.3.1 Changing the circuit of the servo to access the value of internal potentiometer

The internal structure of the servo is as illustrated below:

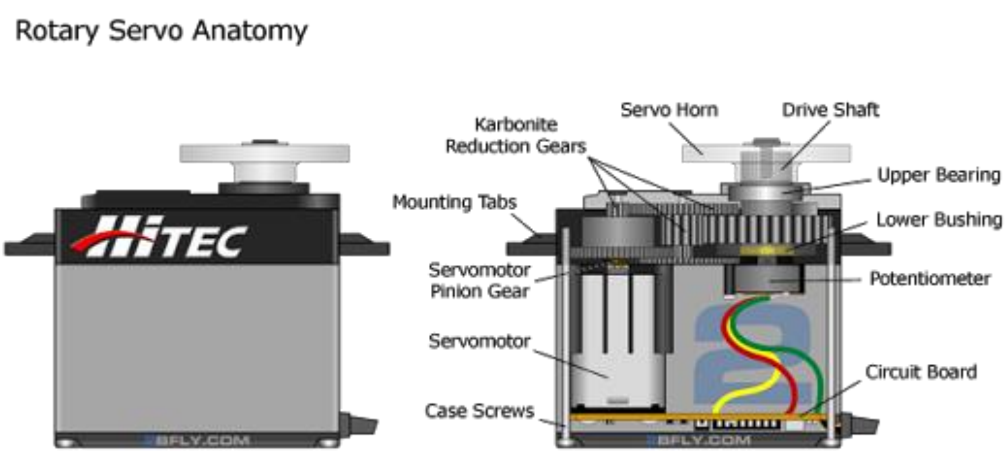


Figure 31: Servo Motor internal structure

We have three wires coming out from the casing as

- Ground
- Power
- Signal

The signal wire carries the signal for turning the servo and can turn the servo in clockwise and anticlockwise direction depending upon the code and requirements.

The problem occurs only because of the fact that we can write a value to this wire but we cannot read any value back from this wire to know the current state of servo.

We did some research on how a servo works and found a potential spot that we could exploit

The potentiometer is directly attached to the servo arm and the middle pin of the servo can be used to provide some input to Arduino on any of the analog pins A0-A5 (A2 in our case) to get the value of minimum angle and the max angle and then map it to a specific range 0 to 180 degrees.

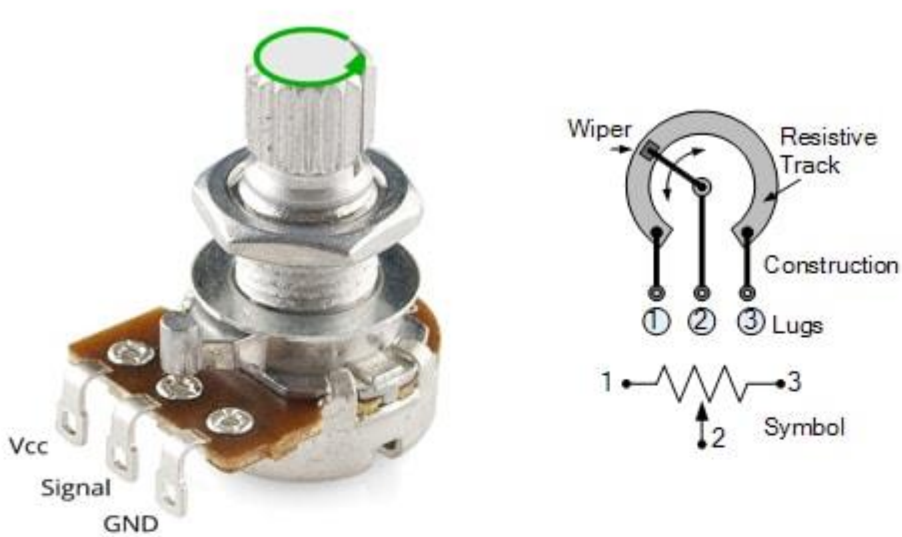


Figure 32: Potentiometer

6.3.2 Details of Hardware Components Used in The Final Version

The internal hardware components of the digital goniometer make up the circuitry responsible for measuring the flexion angle of knees and displaying it on the screen. Additionally, this angle is entered into the mobile application to give out the final score of the knee.

Following are the hardware / electronic components used in the goniometer

6.3.2.1 Arduino

ATmega328P microcontroller is used in Arduino with a combo of 6 Analogue,14 digital I/0 pins and 6 out of these 14 can also be used for PWM outputs. It’s a complete solution for making small projects you just have to code, compile and upload your code and Arduino will take care of the rest it’s a plug and play kind of scenario.
Features of the

- **Microcontroller:** Microchip ATmega328P
- **Clock Speed:** 16 MHz
- **Power Sources:** DC Power Jack & USB Port
- **Flash Memory:** 32 KB, of which 0.5 KB is used by the bootloader
- **SRAM:** 2 KB
- **EEPROM:** 1 KB

Special Pin Functions:

- **PWM (pulse-width modulation):** pins 3, 5, 6, 9, 10, and 11. Can provide 8-bit PWM output with the analogWrite() function.
- **SPI (Serial Peripheral Interface):** pins 10 (SS), 11 (MOSI), 12 (MISO), and 13 (SCK). These pins support SPI communication using the SPI library.

Figure 33: Arduino UNO

6.3.2.2 Servo Motor

A servo motor is a module that rotates with a high degree of precision. A control circuit is frequently included with servo motors to provide feedback on the current position of the motor shaft; this feedback allows the motors to rotate with great precision. A servo motor is used to rotate an object at specified angles or distances, and it is simply made consisting of a simple motor that works through a servo mechanism.

It consists of three parts:

1. Controlled device
1. Output sensor
2. Feedback system

Servo motor works on **PWM (Pulse width modulation)** principle, meaning its rotation angle is controlled by the duration of applied pulse to its Control PIN. A servo motor is made up of a **DC motor controlled by a variable resistor (potentiometer)** and some gears.

Figure 34: Servo Motor

6.3.2.3 LCD Display 16x2

The abbreviation "LCD" stands for "liquid crystal display." It's a form of semiconductor display module that can be found in a wide assortment of circuits and devices, such as phones, calculators, computers, and televisions. The most typical uses for these displays are multi-segment led and seven segments. The main benefits of using this module are its low cost, ease of creating animations, and the fact that there are no limitations on showing unique symbols, nd even animations, and so on.

Figure 35: LCD Display 16x2

Chapter 7: Market Analysis

Commercialization of any project requires a complete market analysis on the basis of which a business plan is created. The market analysis helps in figuring out not only the need but also the demand of the device. The key objective is establishing that there is in fact a market in which this is a sellable device and that demand will be enough to generate suitable profits to sustain a business that can in the long run grow and invest in further research and development.

7.1 Market Size

The market size is considerable as there are a lot of people not only in Pakistan but also in the world who suffer from Osteoarthritis. Statistics from WHO, NIH and UN show that there is a considerable market in this industry that can be targeted.

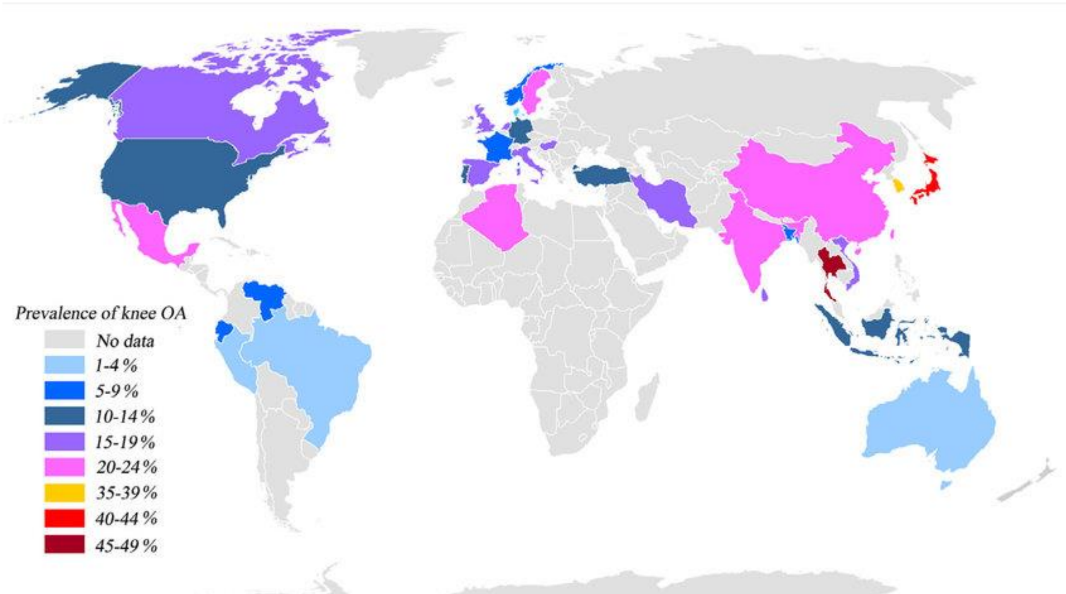


Figure 36: Prevalence of knee OA in the world

7.2 SWOT Analysis

A SWOT analysis helps a business analyze its strengths, weaknesses, opportunities and threats. Having oversight of such things enables a business to succeed in the market and be a better competitor. Our SWOT analysis shows that although we have existing threats and weaknesses the opportunity at hand is too good to be thrown away. In a market that is largely untapped, people who suffer from disorders and difficulties along with completed research and obtained funding give us the perfect platform to succeed.

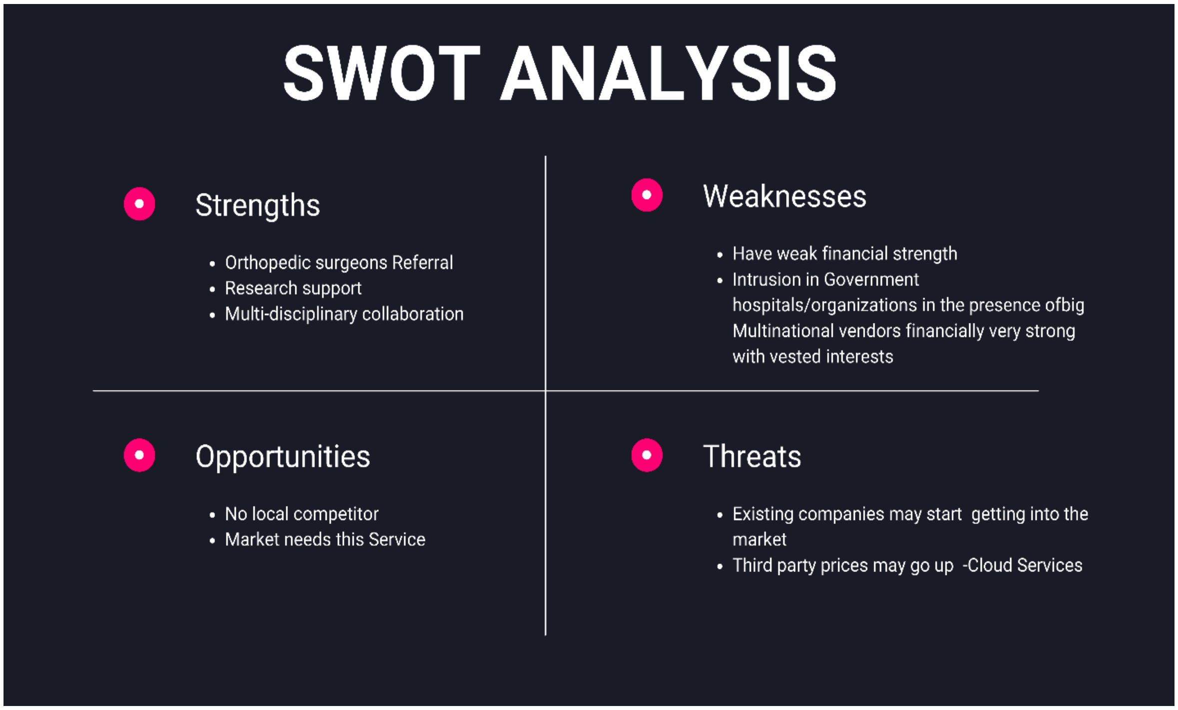


Figure 37: SWOT Analysis

7.3 Four P's

The four Ps are product, price, place, and promotion. They are an example of a "marketing mix," or the combined tools and methodologies used by marketers to achieve their marketing objectives.

Given below are the four P's for OSTEO-DOC:

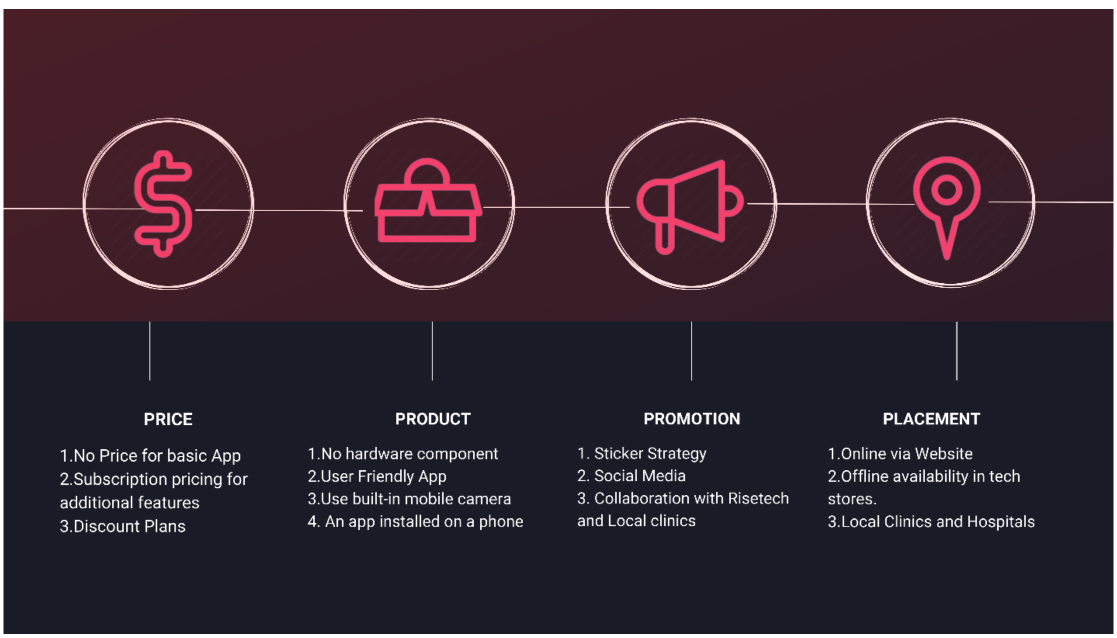


Figure 38: Marketing Strategy

Chapter 8: Conclusion and future work

8.1 Conclusion

Thus, through above observation experimentation we can see that the results of architectures with more depth and larger parameter size performed relatively well as compared to the ones having low depth and input parameters. We also need solutions which are not just focusing on the classification part through deep learning but also focus on some known parameters which can provide us with some insights and customized diagnosis for each patient. Involvement of medical professionals is crucial in development of such systems to ensure a smooth and trustworthy medical diagnosis support systems.

8.2 Future Prospects

The project has great prospects in the future. As a complete product there are multiple new ways to make it even better and provide more development work. Many of the planned improvements could not be implemented due to time constraints. We hope that these recommendations will be taken with a positive outlook and will be worked on with great zeal.

An organizational version of the system can be developed which can serve the purpose of operating in a hospital or clinic where there is a need to serve multiple diseases at the same time and can be used for consultation with other doctors as well.

Furthermore, there is currently no compiled data available of people suffering from Osteoarthritis in Pakistan and if we gain mass adoption then we will have the first database of such people and can gain profit from that data by either selling it or providing consultancy services.

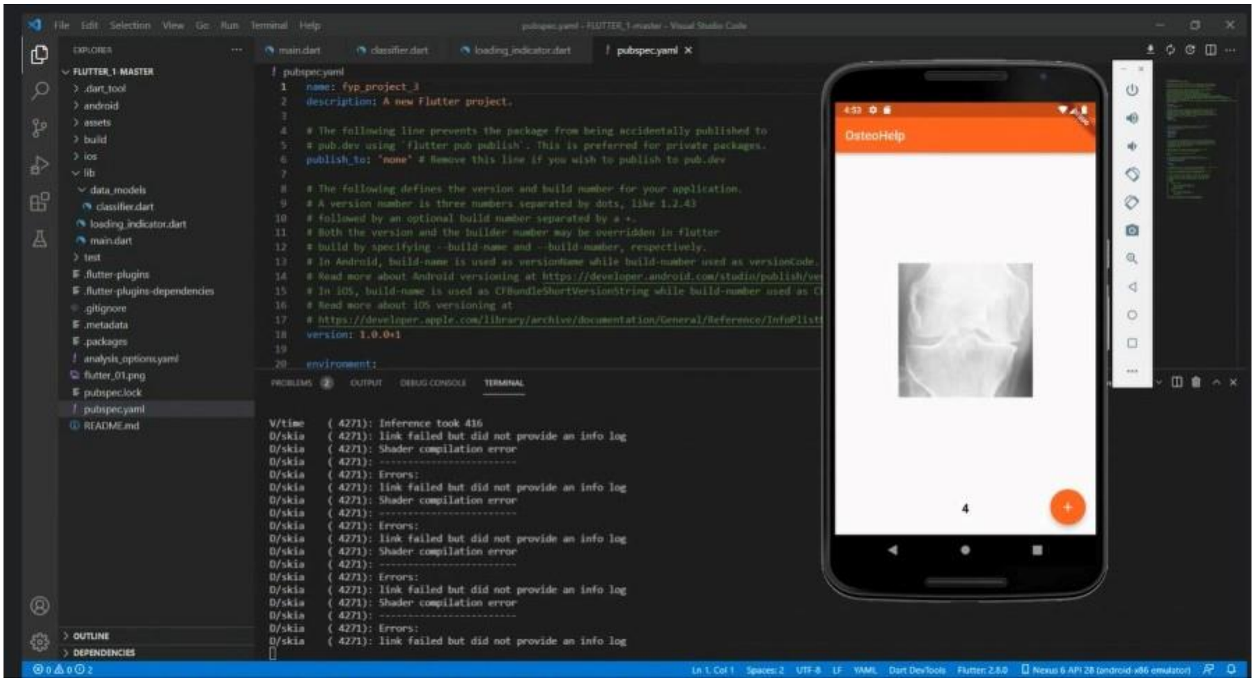
UX can be further improved specially the KOOS questionnaire part as it takes around 2-3 minutes to fill it and average concentration span of our test cases was on an average 30 seconds.

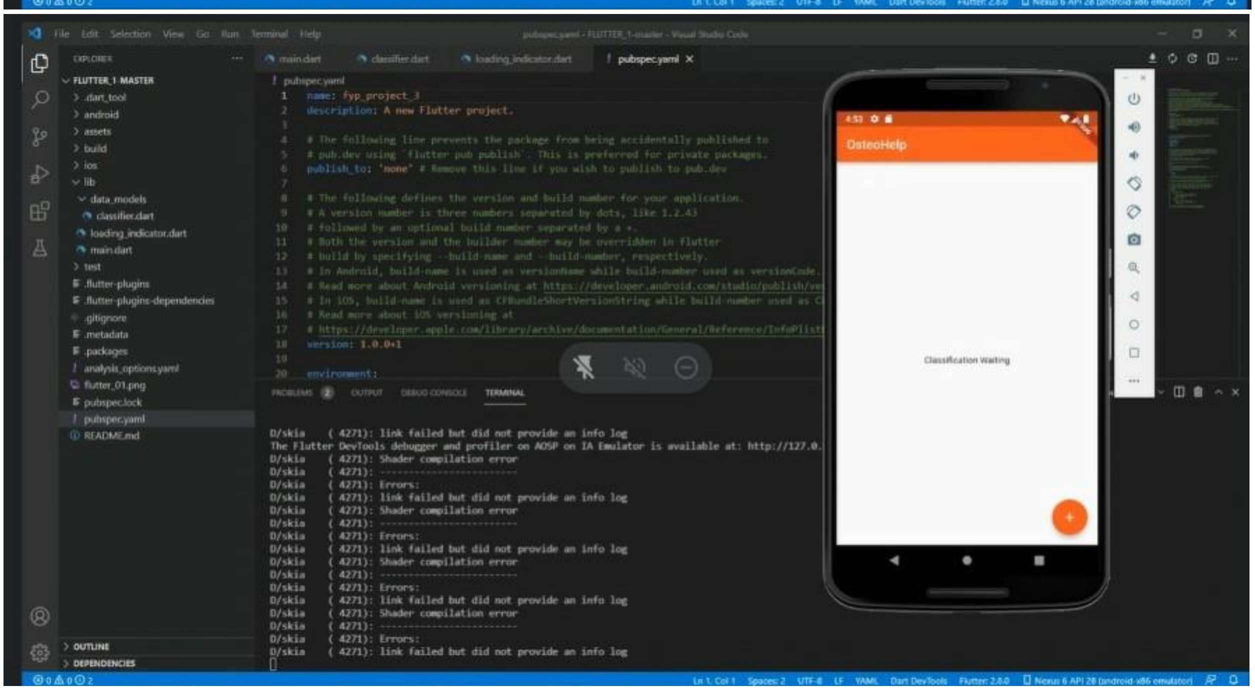
Additional features like classification of patients by looking at their history and knee Xray segmentation to compare two X-Ray of the same person over a span of some time period may also be helpful.

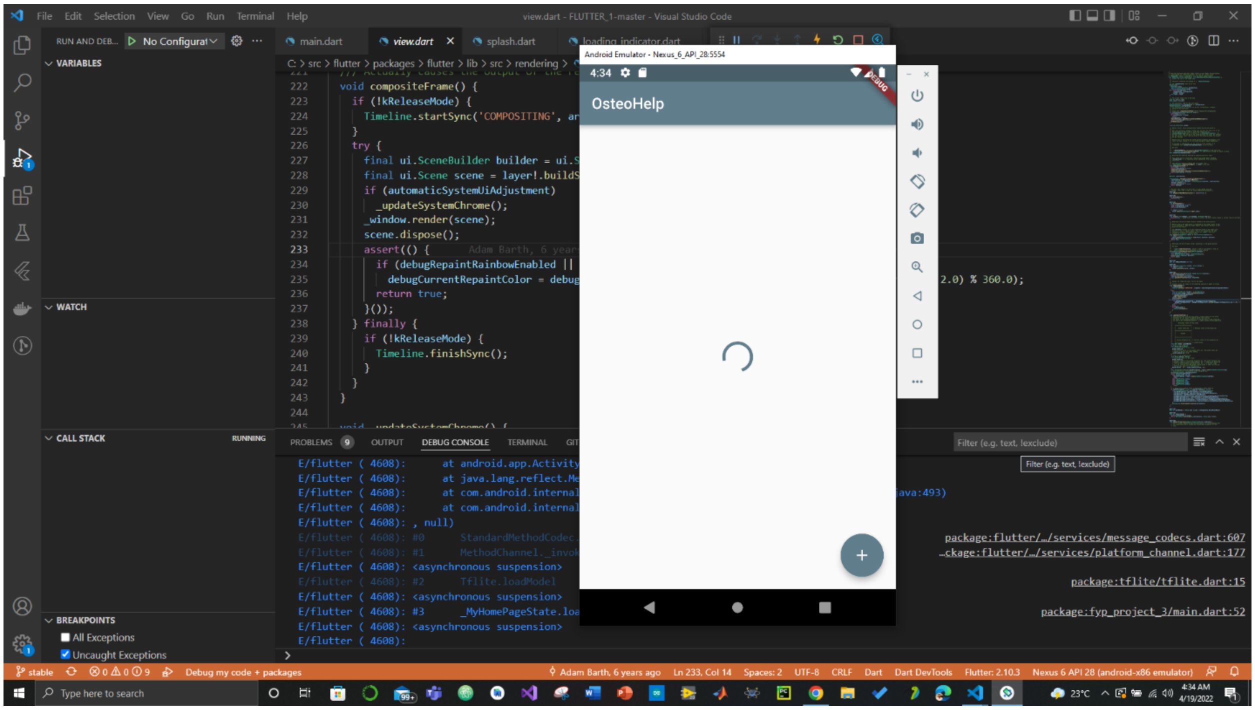
Goniometer can be further improved structurally by 3D printing a solid skeletal structure for mass adoption and fabrication.

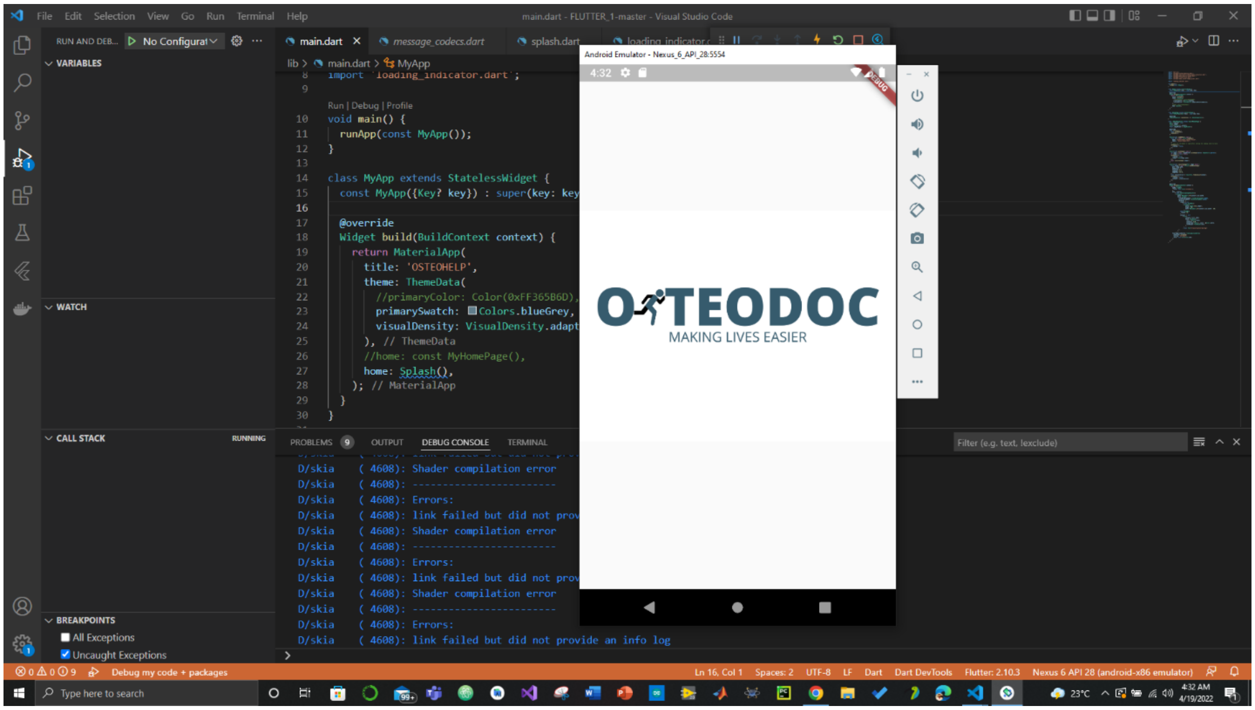
Appendix A

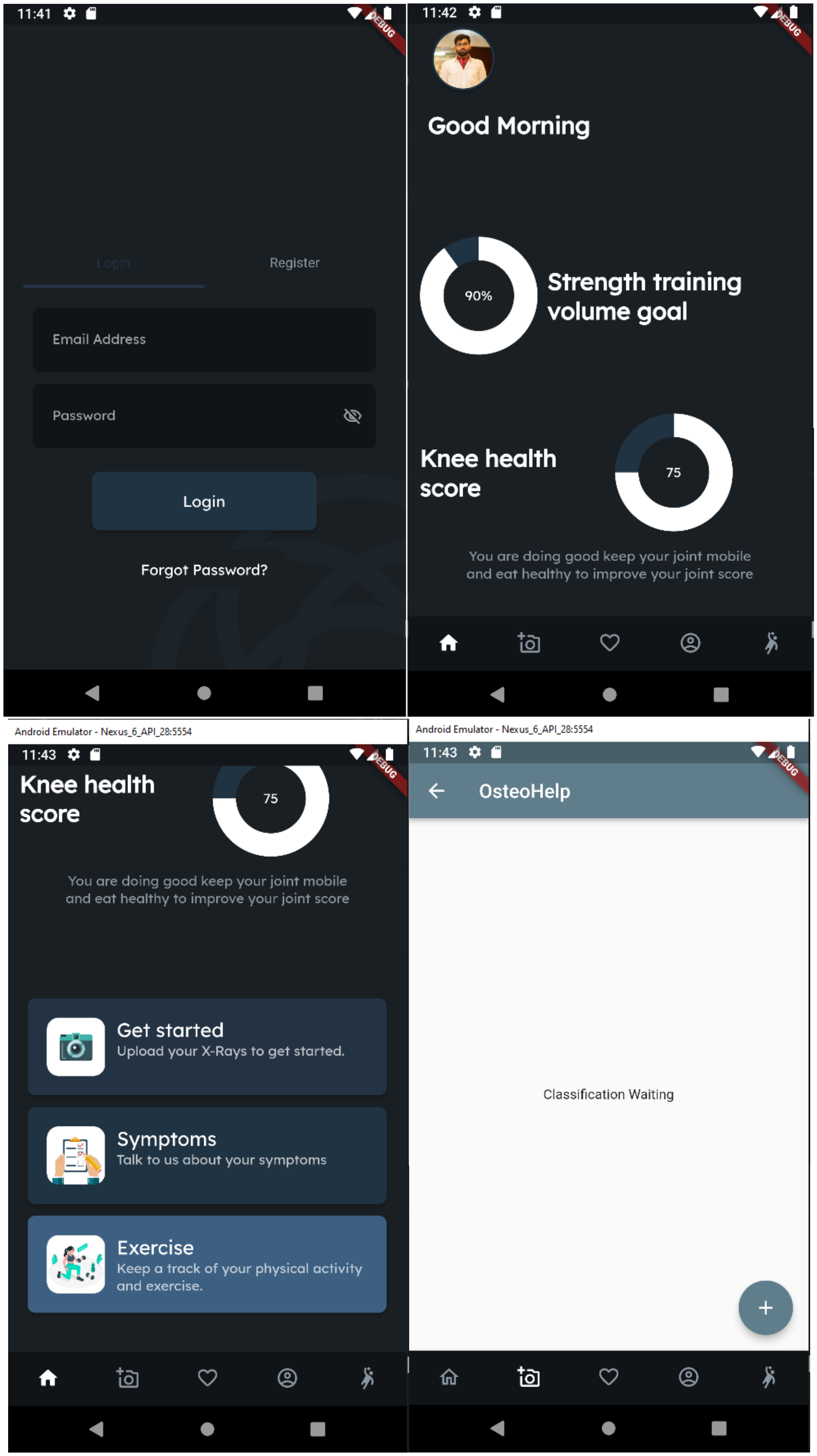
Software Evolution

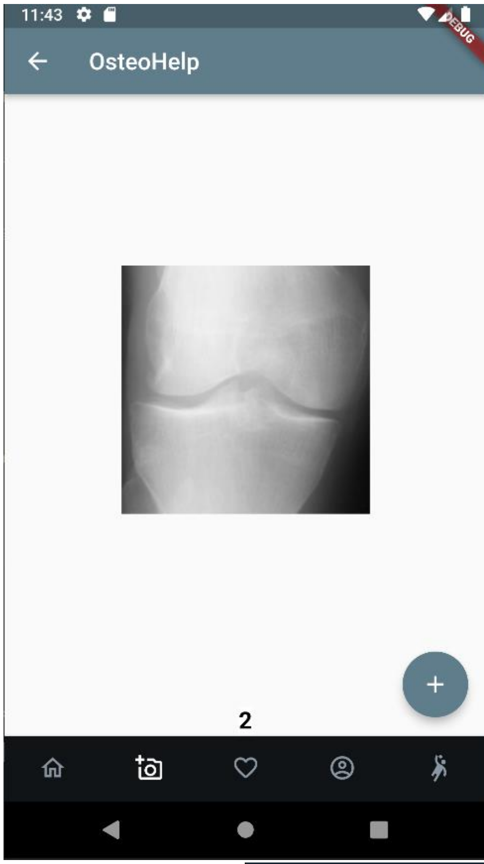


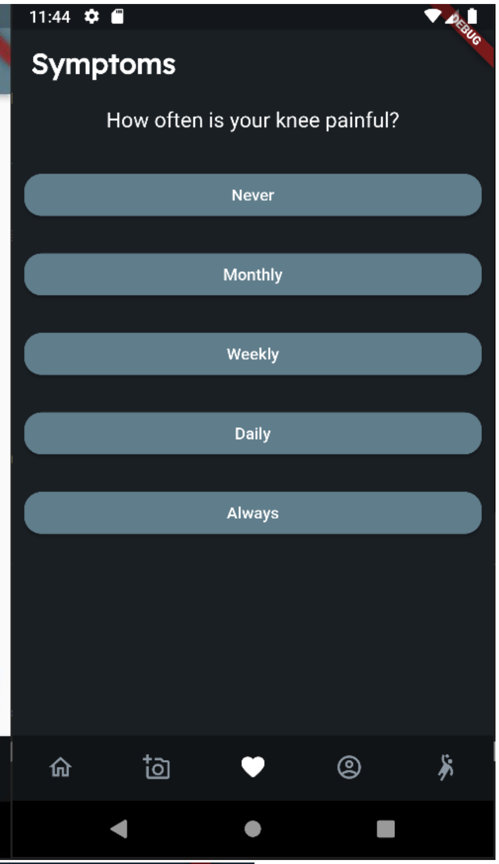


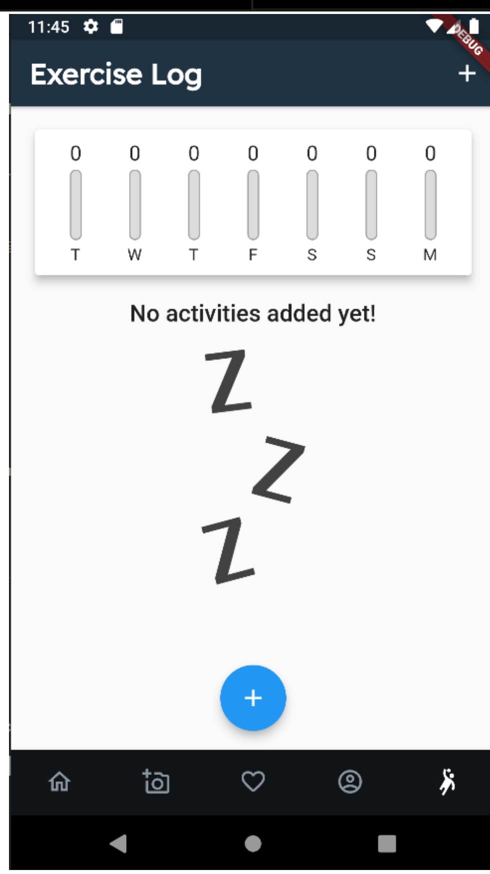




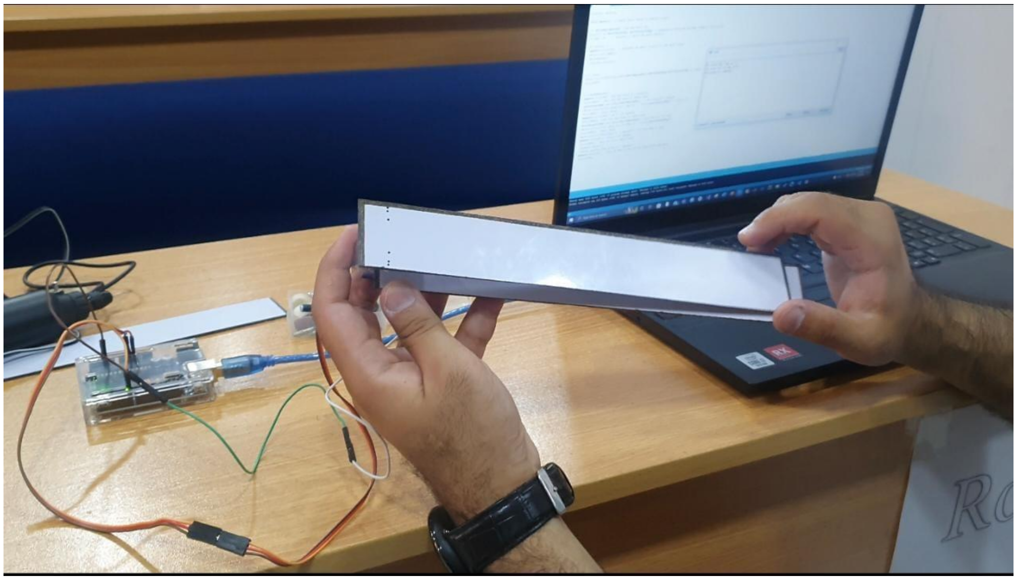

11:41
DEBUG
Login
Register
Email Address
Password
Login
Forgot Password?
11:42
DEBUG
Good Morning
90%
Strength training volume goal
Knee health score
75
You are doing good keep your joint mobile and eat healthy to improve your joint score
Android Emulator - Nexus_6_API_28:5554
11:43
DEBUG
Knee health score
75
You are doing good keep your joint mobile and eat healthy to improve your joint score
Get started
Upload your X-Rays to get started.
Symptoms
Talk to us about your symptoms
Exercise
Keep a track of your physical activity and exercise.
Android Emulator - Nexus_6_API_28:5554
11:43
DEBUG
OsteoHelp
Classification Waiting
+

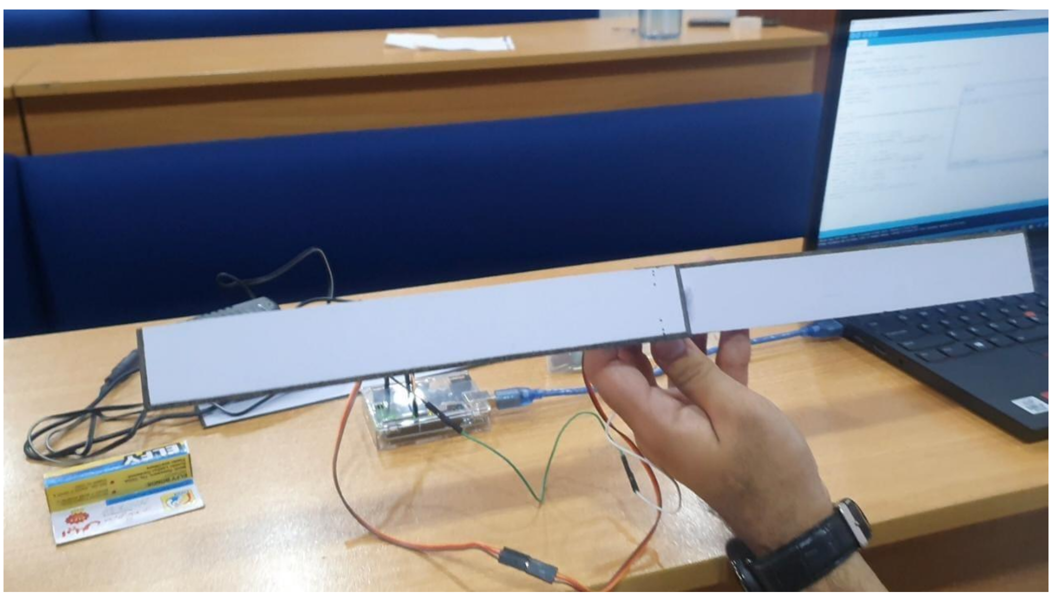

11:43
DEBUG
OsteoHelp
2

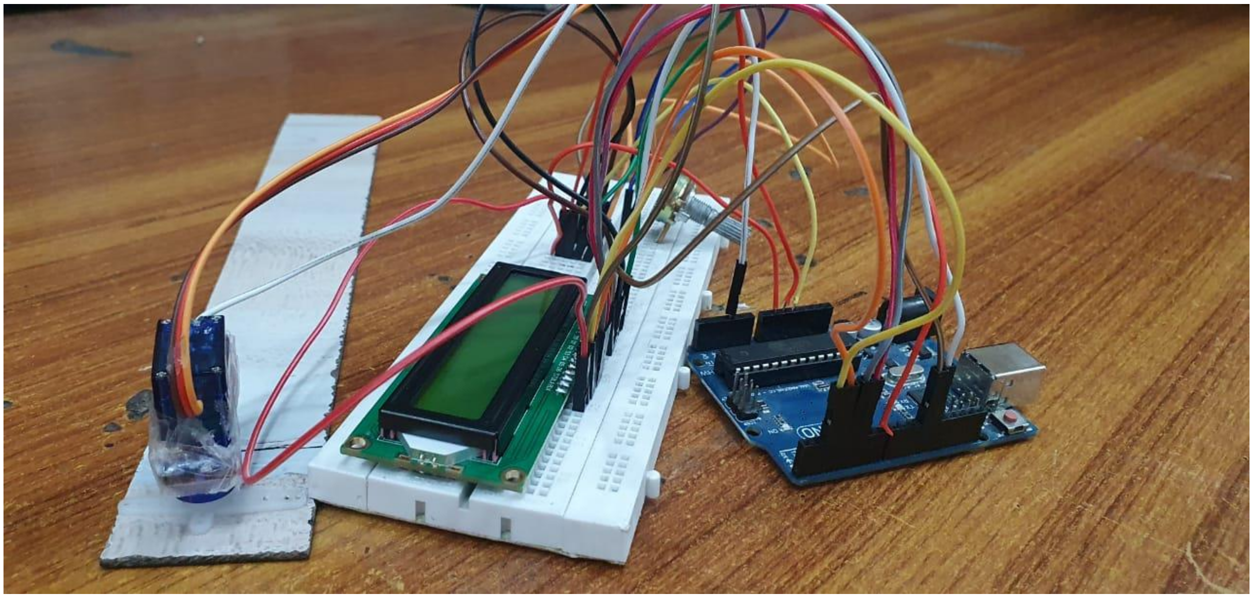

11:44
DEBUG
Symptoms
How often is your knee painful?
Never
Monthly
Weekly
Daily
Always

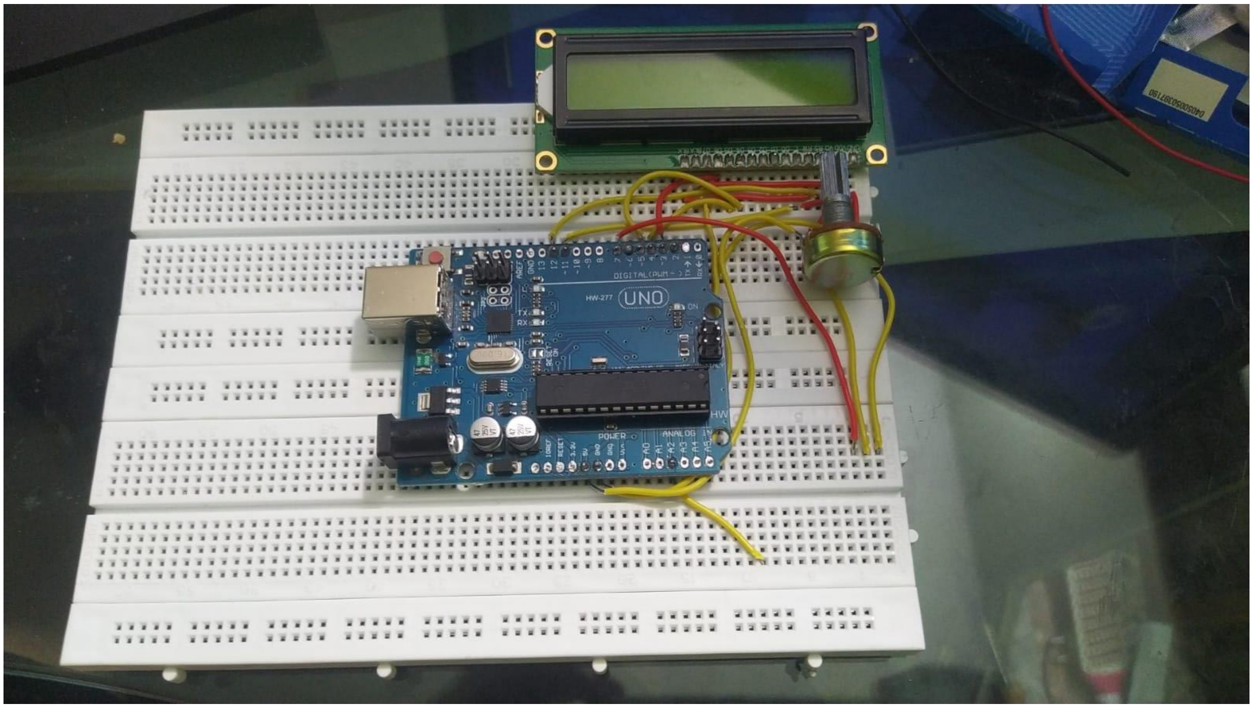

11:45
DEBUG
Exercise Log
0 0 0 0 0 0 0
T W T F S S M
No activities added yet!
Z
Z
Z

Hardware Evolution









Code to run the Hardware:

```
#include <LiquidCrystal.h>
#include <Servo.h>
Servo myservo;  // create servo object to control a servo
int servoAnalogOut=A2; //The new Servo Pin
unsigned int servoValue0Deg, servoValue180Deg; // Vaiables to store min and max values of servo's pot
int pos = 0;    // variable to store the servo position
const int rs = 12, en = 11, d4 = 5, d5 = 4, d6 = 3, d7 = 2;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
float number;
void setup() {
  myservo.attach(7);  // attaches the servo on pin 9 to the servo object
  Serial.begin(9600);
  calibration();
  lcd.begin(16, 2);
  lcd.print("GONIO ANGLE:");
}
void loop() {
  lcd.setCursor(0, 1);
  number= 0;
  number = map(analogRead(servoAnalogOut),servoValue0Deg,servoValue180Deg, 0, 180);
  lcd.print(number);
  Serial.println(number);
  delay(500);
}
void calibration(){
  myservo.write(0); //set the servo to 0 position
  delay(500); //wait for the servo to reach there
  servoValue0Deg= analogRead(servoAnalogOut); // Pot value at 0 degrees
  Serial.println("Pot value for 0 deg is " + String(servoValue0Deg)); // Print it!
  delay(500); //fancy delay
  myservo.write(180); //go to 180 degrees
  delay(500); //wait for the servo to reach there
  servoValue180Deg= analogRead(servoAnalogOut); //pot value at 180 deg
  Serial.println("Pot value for 180 deg is " + String(servoValue0Deg));
  delay(500); //fancy delay
  Serial.println("Now going to 0 Degrees"); //It does what it says
  myservo.write(0);// going to 90 degrees
  delay(5000);// wait for it to reach there
  myservo.detach(); // stop the PWM so that we can freely move the servo
  delay(500);

}
```

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