KNEE OSTEOARTHRITIS PREDICTION AND PROGRESSION USING MULTI-MODAL DEEP LEARNING.

Project ID: 25-26J-112

Project Proposal Report

Jayasinghe J.M.N.S – IT22582942

BSc (Hons) in Information Technology Specializing in Data Science

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Declaration

We declare that this is our own work, and this proposal does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of our knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Name	Student ID	Signature
Jayasinghe J.M.N.S.	IT22582942	

The supervisor/s should certify the proposal report with the following declaration.

The above candidates are carrying out research for the undergraduate dissertations under my supervision.

Signature of the Supervisor — Date

.... 2025/08/29

(Ms. Jenny Krishara)

Signature of the Co-supervisor — Date

.... 29/08/2025

(Ms. Wishalya Tissera)

Abstract

Osteoarthritis (OA) is a degenerative joint disease marked by the gradual breakdown of cartilage and changes in the underlying bone. The condition is most prevalent in older adults and is often exacerbated by joint injuries and mechanical stress. Knee osteoarthritis (KOA) is one of the common disabilities adjusted life years. Although KOA has no permanent cure, but a combination of lifestyle changes, medications, physical therapies, and sometimes knee transplants can help manage the condition.

Currently, diagnosis and monitoring of KOA relies on X-rays, MRI scans, and clinical assessments. However, these methods have notable limitations, they are costly, require specialized equipment, are accessible mainly in large hospitals. Furthermore, these tools only capture the knee's condition at a single point in time, which is not comprehensive due to its slow progression. Since KOA progresses slowly and changes over weeks or months, one-time imaging does not provide a complete view of how the disease is developing, which can be challenging for older adults or those with mobility issues. Additionally, tests focus on only one type of data, reducing treatment accuracy.

To address these challenges, this research proposes a system with four main components.

1. Disease Prediction through the analysis of X-ray and MRI images.
2. Clinical, Biomarker, and Demographic Data Modeling for enhanced disease prediction.
3. KOA Severity Grading using both clinical data and imaging data (X-ray/MRI).
4. Smart IoT-Based Knee Health Monitoring leveraging VAG signals.

The system leverages a multi-modal deep learning model that integrates patient demographics, clinical symptoms, biomarkers, and imaging data to predict KOA progression and severity. The system can provide a more complete and personalized view of the patient’s knee condition. Continuous monitoring allows for regular updates on disease progression, severity allowing timely intervention and better long-term care. In addition, the use of explainable AI improves trust by making predictions and decisions more transparent for both healthcare providers and patients.

The expected outcome of this research is a low cost, accessible, and real time solution for KOA prediction, monitoring, and management, especially in rural and low resource environments. This document focuses mainly on predicting the presence/absence of KOA using demographic, clinical and biomarker data.

Keywords: Knee Osteoarthritis, Demographic data, Clinical data, Biomarker data, Machine Learning

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List Of Abbreviations

Abbreviation	Description
KOA	Knee Osteoarthritis
VAG	Vibroarthrography
AI	Artificial Intelligence
ML	Machine Learning
SVM	Support Vector Machine
MRI	Magnetic Resonance Imaging
CRP	C- Reactive Protein
COMP	Cartilage Oligomeric Matrix Protein
CTX	Cerebrotendinous Xanthomatosis
IoT	Internet of Things
CT	Computed Tomography

1.Introduction

KOA is a degenerative joint disease that progressively involves the breakdown of articular cartilage, alterations in subchondral bone and the emergence of chronic pain, stiffness and loss of mobility. It ranks among the most common causes of disability in the global population, where it is over-represented among older adults and the obese population [9], [10]. The rising prevalence of KOA in the world today due to a rising aging population and the rising incidences of obesity in individuals has been a significant burden to health care systems. This is why early identification and preventive measures are thus important in order to enhance patient outcomes and lower healthcare costs over time.

The use of the conventional diagnostic methods, including X rays, CT and MRI are still the gold standard in identifying KOA. Such techniques, however, tend to be constrained by depending on observable structural alterations that normally manifest in late stages of the disease. In addition, imaging modalities are also expensive, contaminate patients with radiations (X-rays and CT), and they need to be interpreted by experts to be more convenient in the early diagnosis and continuous monitoring [7]. Such delay in diagnosis limits the availability of preventative treatment and leads to the disease development before the effective intervention can be presented.

Recent studies have also found the need to combine various data sources to predict KOA. Age, sex, BMI, the level of physical activity, and the past knee injury have been clinically and demographically shown to have significant impacts on the occurrence and progression of the disease [2], [4]. Moreover, molecular and biochemical biomarkers, such as blood-based protein markers and inflammatory markers, have shown the possibility of enhancing diagnostic accuracy and the possibility of earlier detection [1], [3], [8]. The multi-modal data streams can be combined to enable researchers to better capture the complex interactions that lead to KOA development.

Methods of ML have also developed this discipline through a more powerful analysis of big data consisting of heterogeneous sets. Such algorithms as SVM, Random Forests, and deep learning models have the ability to reveal very small patterns and associations between clinical, demographic, and biomarker variables that would be difficult to reveal using conventional statistics [2], [5], [6]. These predictive methods have delivered favorable outcomes and these methods have provided better accuracy in the diagnosis of KOA besides giving predictive power regarding the future course of the condition. Nonetheless, the most current literature has been on single data modalities, thereby constraining diagnostic reliability and applicability in different groups of patients [7].

The current study is aimed at to mitigating these weaknesses by suggesting the creation of a machine learning-driven KOA prediction framework that combines demographic, clinical, and biomarker variables. Through such multi-mode strategy, the objective of the system is to more accurately and reliably predict the presence or absence of KOA in an individual than by standard methods. Finally, this predictive framework can potentially aid previous clinical-intervention, improve patient care, and decrease the prolonged burden of KOA on healthcare systems.

1.1 Background & Literature survey

KOA is a widespread degenerative disorder of the joints that leads to gradual destruction of cartilages of the joints, producing pain, stiffness, and lack of mobility in the joints. It is mostly common among the older adults and ranked as one of the top causes of disability in the world [9], [10]. The KOA is on the rise with the aging world population and the increase of the obesity rate and presents a huge burden to health care systems. In addition to the physical restrictions, KOA also lowers quality of life and causes financial constraints based on the long-term treatment and productivity loss [9]. Early diagnosis and prognosis are thus needed to slow down the development of the disease and enhance the well-being of the patient [10].

Conventional methods of diagnosis are based mainly on imaging, i.e., on X-rays, MRI, which, despite its efficiency, has significant limitations. Radiographs tend to detect KOA only at advanced stages when structural alterations can be detected, whereas MRI is more detailed and visualizes soft tissues and cartilages but is still expensive and unavailable to perform a regular screening [7]. Such a restriction is critical to the need to identify other sources of data so that they can predict at an earlier stage and more accurately.

Recently, studies have focused on the importance of clinical, demographic and biomarker information in predicting KOA. The severity of pain, functional impairments, and previous injuries, demographic variables (age, sex, and BMI) have been identified to display close associations with KOA onset and progression [2], [4]. Also, biomarkers have surfaced as the promising disease activity indicators. As an illustration, blood-based biomarkers, e.g.,CRP, and CTX-II, can help to better understand cartilage metabolism and inflammation [3], [8].

Machine learning and AI have redesigned the way these various datasets are analyzed, providing sophisticated models capable of revealing latent patterns and sophisticated relationships between predictors. SVM algorithms, as well as random forests and deep learning, have been used to predict the presence of KOA with promising levels of accuracy [2], [5]. A critical review of AI-based KOA studies notes that they have great potential but leave gaps in terms of integrating multi-modal data, different measures of evaluation, or a lack of clinical validation [6], [7].

In spite of these developments, the majority of the current research centers on one data form, be it imaging, clinical or biomarker data without recent efforts to form coherent multi-modal structures. Moreover, although prediction models have demonstrated potential, they have not been utilized to date in clinical practice because of generalizability and interpretability concerns. Solving these gaps via a solution where demographic, clinical, and biomarker data will be integrated will not only enhance the quality of diagnosis, but will also help in the earlier detection making KOA prediction more practical and actionable within healthcare settings.

1.2 Research Gap

KOA is highly influenced by clinical conditions, demographic variables and biomarkers. The current studies address mainly either the demographic data or clinical variables, however, small number of researches have been done regarding machine learning methods in various conditions. The study will combine clinical, demographic and biomarker data to come up with improved prediction on KOA.

To achieve diagnostic accuracy and early risk identification, several studies have examined the prediction of KOA by using different clinical, demographic, and biomarker information and applying different machine learning algorithms.

W. Chen et al., 2025 – Identification of biomarkers for knee osteoarthritis through clinical data and machine learning models

In order to forecast the risk of osteoarthritis in the knee, this study examined clinical and biomarker data. Their method revealed important predictors that influence KOA and showed that the random forest model outperformed other algorithms in terms of diagnostic accuracy.

G. Schadler et al., 2022 - The association of blood biomarkers and body mass index in knee osteoarthritis: a cross-sectional study

This study examined the association between the serum biomarkers and BMI in patients with KOA. Using a cross-sectional design, the researchers determined the biomarker levels, including the adipokines and inflammatory markers, as well as BMI to study their combined influence on KOA progression. Results demonstrated a significant association between elevated BMI and increased levels of certain biomarkers, which has identified obesity not only as a mechanical risk factor, but also as a metabolic pathway to KOA.

L. Lourido et al., 2021 – A clinical model including protein biomarkers predicts radiographic knee osteoarthritis: a prospective study using data from the Osteoarthritis Initiative

This research developed a clinical-biomarker model to predict the future development of radiographic KOA. By analyzing protein levels together with biomarker and clinical variables, the researchers were able identify whether a person is having KOA or not.

L. S. Lee, P. K. Chan et al., 2022 - Artificial intelligence in diagnosis of knee osteoarthritis and prediction of arthroplasty outcomes: a review

In this paper, the application of AI approaches, specifically machine learning and deep learning, to diagnosing KOA and in predicting outcomes following knee arthroplasty was reviewed. The authors reviewed how imaging (x-rays, MRI) and clinical features have been applied in AI models to characterize KOA severity, determine risk factors, and predict progression. They also highlighted the role of AI in surgical predictions in the form of recovery level, as well as the prediction of revision surgery after knee replacement. Reported models showed encouraging levels of accuracy both for diagnosis and for prognosis.

Feature / Aspect	**W.Chen 2025**	**L.S.Lee 2022**	**L. Lourido 2021**	**Proposed System**
Focus on demographic data	No ✕	No ✕	No ✕	Yes ☑
Focus on clinical data	Yes ☑	Yes ☑	Yes ☑	Yes ☑
Focus on Biomarkers	Yes ☑	No ✕	Yes ☑	Yes ☑
Use ML for predictions	No ✕	Yes ☑	No ✕	Yes ☑
Prediction based on a multi model	Yes ☑	No ✕	Yes ☑	Yes ☑

Table 1: Comparison of former research.

1.3 Research Problem

The key issue with KOA care is that it is hard to identify the disease at an early stage and correctly determine its presence. The existing diagnostic tests like X-rays and MRI scan can be employed in detecting KOA, however, these tests are usually done at late stages when a structural damage is evident. All of these methods are not always available, need hospital visits and rely on expert interpretation, restricting their use as a regular screen. Consequently, most patients are diagnosed later when the disease is at an advanced stage, which decreases the potential of early treatment.

The other problem is that the majority of today existing diagnostic methods focus on imaging, and other valuable data, including patient demographics, clinical history, and biomarker data, are not used to the full extent. Research has demonstrated that age, sex,BMI, history of previous injuries, and blood biomarkers are good predictors of the KOA risk although these data have seldom been incorporated in a single predictive model. This poses a gap in giving a more comprehensive and true evaluation of whether or not a patient is having KOA.

An even bigger challenge is presented to patients in resource limited or rural settings where advanced imaging equipment is not always present. Lack of available and data-driven predictive systems results in the possibility that early markers of KOA can be missed, accelerating the progression of the disease, decreasing mobility, and elevating the possibility of disability.

An effective demographic, clinical, and biomarker-based prediction model can be a feasible answer to a cost-effective solution. The examination of various sources of data simultaneously can enhance accuracy in identifying when a patient has KOA, assist with the earlier identification of it, and assist a doctor in making more informed decisions in urban and rural healthcare facilities.

2. Objectives

2.1 Main Objective

The main objective of this research is to implement a software base system to early prediction and identify the progression of KOA, by integrating clinical, demographic and biomarker data. Therefore,

1. Predicting the presence of KOA accurately through clinical, biomarker and demographic data using a multi-model.
2. Predicting the presence of KOA using X-ray and MRI images.
3. Identifying the severity level using clinical, biomarker and X-ray/MRI images.
4. Developing a IoT based knee health monitoring system using VAG signals.

2.2 Specific Objectives

1. Multi-Model Data Integration:

Develop a unified system that collects and integrates demographic, clinical, and biomarker data to support accurate prediction of knee osteoarthritis.

2.KOA Prediction

Implement machine learning models capable of predicting whether an individual currently has or hasn’t KOA

3. Methodology

This methodology outlines the development of a machine learning based system that integrates clinical, demographic and biomarker data for early prediction of KOA. It is developed with a sequential workflow ensuring both technical robustness and clinical applicability.

1. Data Collection & Validation
   The information obtained on the patients will be in the form of patient records that will be gathered at the hospital clinics in cooperation with orthopedic specialists. The data will consist of demographics (age, sex, BMI, occupation) clinical (pain, joint stiffness) and biomarkers (CRP).
   Medical personnel will check the quality of datasets, delete disagreements or mislabeled records and validate clinical significance.

2. Data preprocessing and feature engineering
   Cleaning and Normalization: Work with missing values, outliers and unit inconsistencies amongst biomarker measurements.
   Encoding and Transformation: Encode categorical variables
   Feature Engineering: You are to use statistical algorithms to select those features that tend to be most correlated with KOA.

3. Model development
   Selection of the algorithm: Train multiple machine learning models including the Logistic regression, Random Forest and SVM.
   Hyperparameter optimization: Optimize related hyperparameters such as learning rate, regularization and feature sampling.

4. Model Evaluation and Validation:
   Compare model performance in terms of accuracy, sensitivity, precision, recall and F1-score.
   Use k-fold cross validation to help test generalizability.
   test model performance on a dataset of a different clinical origin in order to test robustness.

5. Deployment and Commercialization
   The last system is implemented as a scalable and practical usability system.

3.1 Requirement Analysis

Identify the medical, technical, and user requirements for the prediction of KOA.

Sources of Information:

- Consultations with Orthopedic Doctors and Rheumatologists to learn the clinical presentation of KOA, diagnostic process, and the role of demographic, clinical and biomarker variables in the disease prediction.
- Collect patient and medical records related to demographic details, clinical history and biomarker test results from hospital databases.

3.2 Project Requirements

3.2.1 Functional Requirements

- Data Input Model - The system must allow the input of patient demographic, clinical and biomarker data in to the platform.
- Data Preprocessing - The system must clean, normalize and prepare the input data so it is compatible with the precision model.
- KOA Prediction model - The system must apply a trained machine learning model to predict whether a patient has KOA or not.
- Prediction Output - The system must display the prediction results as a clear outcome.
- Result Storage - The system must store the prediction results along with the patient's input data for future reference and analysis.

3.2.2 Non-Functional Requirements

- **Accuracy:** The system should also offer a high degree of prediction accuracy to allow best KOA detection.
- **Performance:** The system should be able to predict a prediction result to the clinician within several seconds based on the patient data.
- **Scalability:** The system should be in a position to support more records on patients without deterioration of performance.
- **Usability**: The system should be able to offer an easy and user-friendly interface to ensure clinicians and health care workers can input data and derive results quickly.
- **Security**: The system should make sure that patient data (demographic, clinical, biomarker) is secured.

3.2.3 User Requirements

- Physicians desire the system to correctly indicate the presence or absence of KOA in a patient based on the demographic, clinical and biomarker information.
- Physicians desire the predictions outcomes to be shown on a dashboard to be easily interpreted.
- Doctors would like to have predictions stored in the system to refer to them later when they need to follow up the patient.

- Patients desire their health data (demographic, clinical, biomarker) to be maintained in a safe and confidential state.

3.2.4 System Requirements

Software Requirements:

- Programming Language: Python
- Libraries: Numpy, Pandas, Scikit-learn
- Mobile application (Flutter).
- Cloud database (Firebase).
- Google Colab
- GitHub

3.3 System Design

3.3.1 Use Case

Use case ID	UC01
Use case Name	KOA Prediction Using Patient Data
Summary	The system predicts whether a patient has KOA based on demographic, clinical, and biomarker data, and provides the result to the doctor for decision-making.
Priority	High
Pre-condition	• Patient demographic, clinical, and biomarker data are available. • The machine learning model is trained and deployed • The doctor is logged in to the system
Post-condition	• The system provides a KOA prediction result. (Positive/Negative) • The prediction is stored in the database for future analysis
Primary Actor	Doctor
Trigger	The doctor requests a KOA prediction for a patient
Main Scenario	1. Doctor checks a patient. 2. Doctor inputs patient demographic, clinical, and biomarker data. 3. System runs the machine learning model on the data. 4. System generates prediction result (KOA Positive/Negative). 5. Prediction is displayed on the doctor's dashboard. 6. The result is saved in the database for future reference.
Extensions	• If required data is missing → System prompts the doctor to enter missing information. • If the system fails to connect to the database → An error message is displayed.

Table 2*: Use case related to the component*

3.3.2 Sequence Diagram

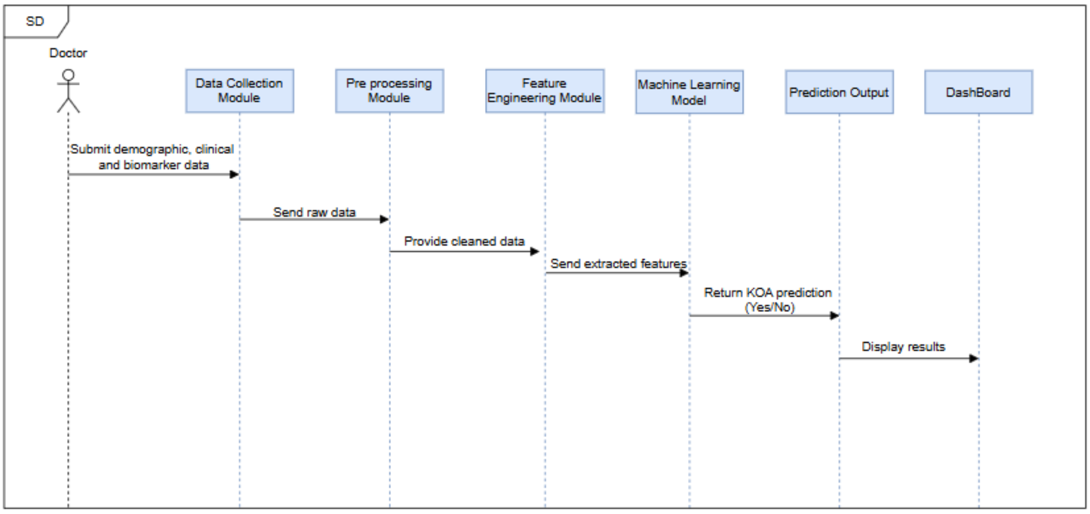

Figure 01 – Sequence Diagram

3.3.3 Overall System Diagram

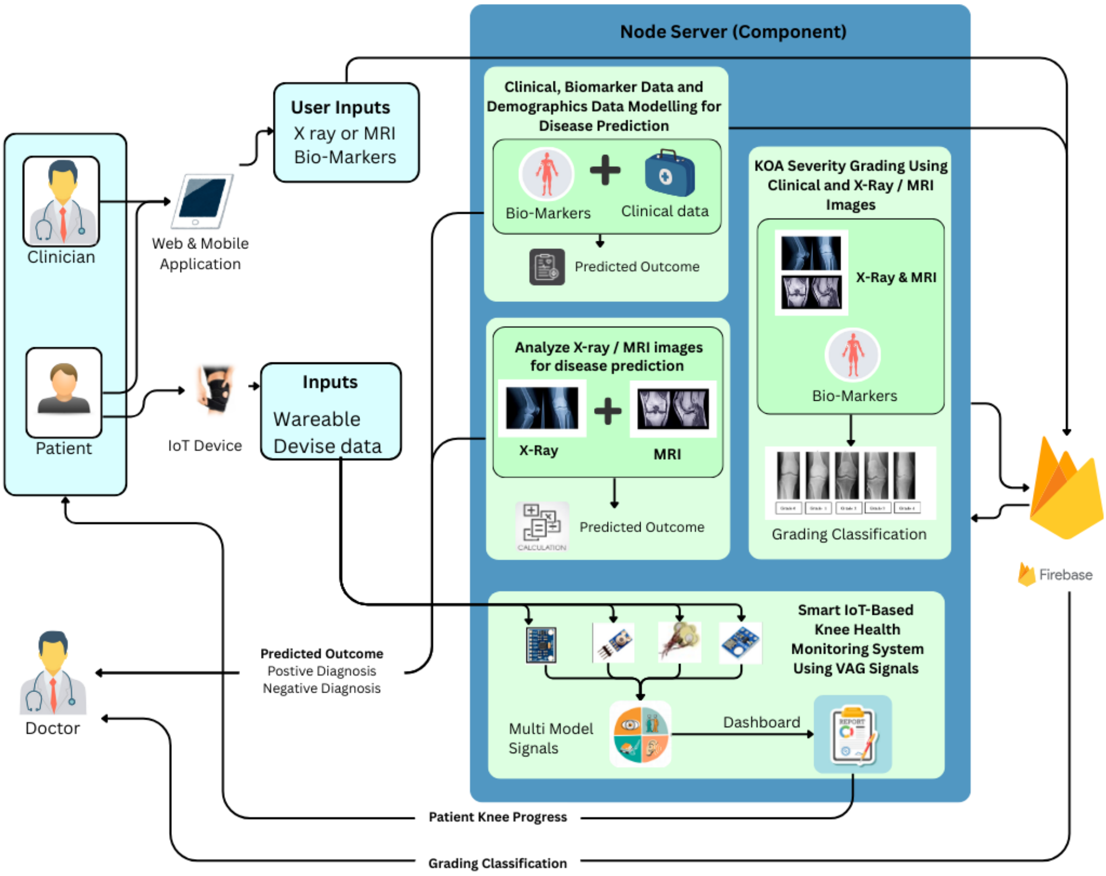

Figure 02 – Overall System Diagram

3.2.4 Component System Diagram

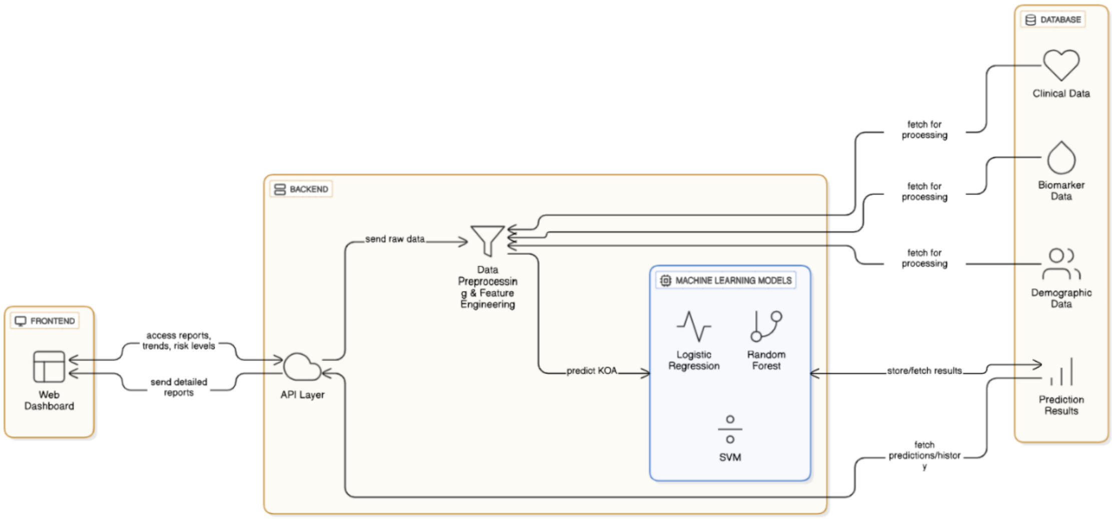

Figure 03 – Component System Diagram

3.4 Development

The development phase covered cloud, and machine learning integration to implement the KOA prediction system using demographics, clinical and biomarker data.

3.4.1 Web and Database Development

Incoming patient data (demographic, clinical and biomarker information) will be handled by an API and a secure web server. A web form will allow doctors to enter or upload patient data, which will be stored in a central database for further processing, logging and prediction.

Technologies - Web server, Database, API

3.4.2 Machine Learning Integration

Features will be extracted from demographic, clinical and biomarker data and used to train a machine learning model in python to predict whether a patient has KOA. The system will integrate preprocessing pipelines, feature selection, and classification algorithms to ensure accurate and efficient predictions.

Technologies – Python, Pandas, NumPy, Scikit-learn, etc.

3.4.3 User Interface Development

A doctor-facing web dashboard will be developed to display patient data and KOA prediction results. The interface will provide clear prediction outcomes, maintain patient history, and support data-driven decision making. Historical records and patient reports will assist clinicians in monitoring long-term trends.

Technologies – React.js, Secure authentication

3.5 Test Plan

The objective of the testing phase will be to confirm the functionality, correctness, reliability, and usability of the KOA prediction system through systematic testing and verification.

Methods -

Unit Testing: Each software component will be tested individually. This includes testing data input forms, API endpoints, database queries, preprocessing pipelines, feature extraction, and machine learning model predictions

Integration Testing: The interactions between the web interface, API, database, and machine learning module will be tested for smooth integration, proper communication, and consistent data flow from input to prediction output.

User Testing: A pilot group of clinicians will use the system to input patient demographic, clinical, and biomarker data. Usability, clarity of prediction results, and overall ease of use will be measured. Feedback will be collected to refine the interface and prediction workflows.

Performance Testing: The system will be tested under varying data volumes and concurrent users to ensure scalability, responsiveness, and accuracy. Prediction response times and dashboard visualization performance will also be evaluated.

3.6 Deployment

The deployment phase will include:

- Hosting the database and server on a cloud or local server.
- Deploying the trained machine learning model as an API service for real-time predictions.
- Releasing a web-based dashboard for clinicians to input patient data and view predictions.
- Ensuring secure authentication and compliance with healthcare data privacy standards.
- Conducting pilot testing in a real-world hospital setting to validate usability and prediction accuracy.

3.7 Work Breakdown Chart

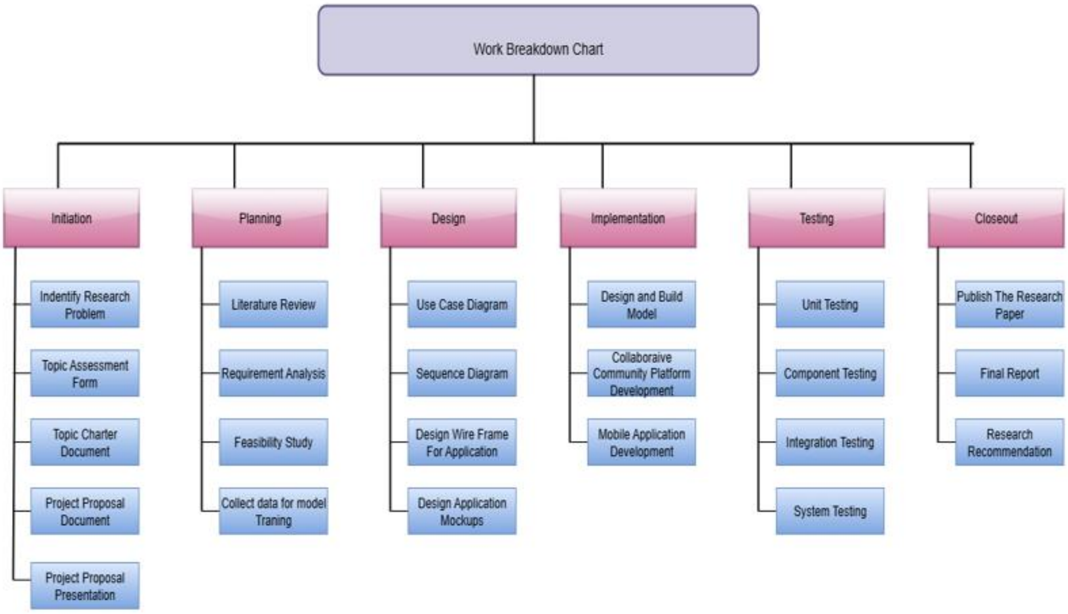

Figure 04 – Work Breakdown Chart

3.8 Gantt Chart

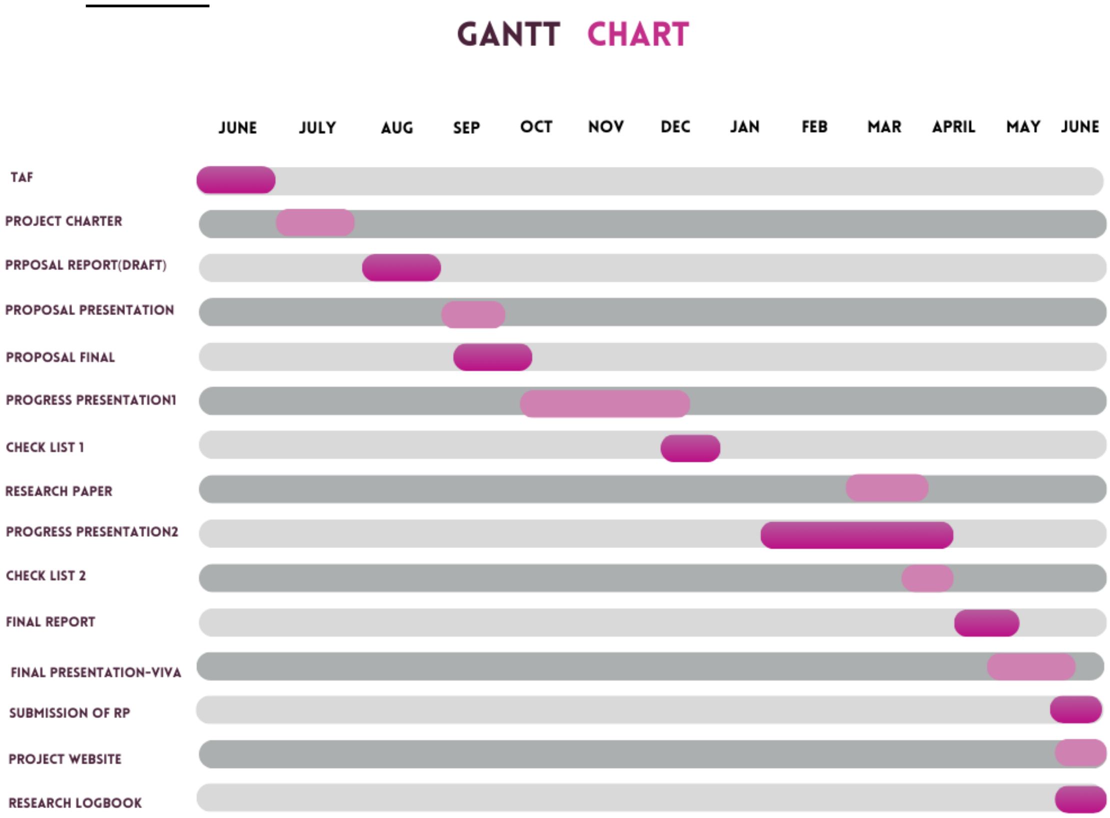

Figure 05 – Gantt Chart

4. Commercialization and Contribution to the Domain

The proposed constituent has good potential for commercialization in the healthcare sector of Sri Lanka, especially in the early diagnosis and treatment of KOA. Osteoarthritis (KOA) represents a major source of disability in the aging population and its prevalence is increasing as a result of the increase in life expectancy and obesity. However, many patients in Sri Lanka are limited by lack of access to advanced imaging facilities, delayed diagnosis and expensive consultation. By providing a predictive analytics ML solution that combines demographic, clinical, and biomarker data, this solution directly addresses these pain points by enabling faster, cheaper, and more accessible screening.

From a commercial standpoint, the system is available as a software product for hospitals, diagnostic laboratories and physiotherapy centers on a subscription or license basis. Hospitals and clinics would be able to incorporate the system into their electronic health records, and smaller health facilities in rural areas could make predictions through a lightweight web/mobile platform, without needing huge infrastructure. Patients would also benefit from an accompanying mobile application that can update their health status and risk assessment along with personalized lifestyle suggestions. In addition, government healthcare organizations and insurance providers may implement the system to support preventive healthcare program systems, decrease treatment costs, and prioritize early interventions.

The contribution to the domain is two-fold, first it fills an important gap between clinical diagnosis and predictive analytics. Traditionally, KOA is evaluated primarily by imaging or symptomatic evaluation and diagnosis is often at a later stage. This module combines demographic, clinical and biomarker data into a single machine learning framework, which enables a comprehensive and earlier prediction of KOA risk. Second, the diagnosis using artificial intelligence is more accurate and consistent, less dependent on subjective assessments, and is more scalable in resource-limited health care systems.

In addition to personalized medication choices, the predictive strength of this platform also serves as a personalization in medicine as the results provide patient-specific risk levels instead of one-fits-all determinations. This enables the clinician to make specific recommendations for interventions such as physiotherapy, weight management or early medical treatment before the disease becomes irreversible.

In brief, commercialization potential is to scale this as a predictive healthcare platform hospital, clinic, and public health programme in Sri Lanka, while academic and industry contribution is to show that artificial intelligence, clinical datasets, and biomarker integration can turn KOA diagnosis into a proactive, low-cost, patient-centric process.

5. Budget and Budget Justification

Requirement	Cost
Internet and Server Hosting	Rs.20000
Travel & Field Visits	Rs. 5000

Table 3*: Budget allocation for the research*

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