Heart Disease Prediction System Using Machine Learning

1. Abstract

Heart disease is one of the leading causes of death worldwide, and early diagnosis is critical for effective treatment and prevention. This project presents a machine learning–based heart disease prediction system that analyzes clinical and demographic patient data to determine the likelihood of heart disease. The system follows a layered architecture that separates data management, preprocessing, model learning, evaluation, explainability, and decision support. Multiple machine learning models are trained and evaluated using healthcare-focused metrics, with an emphasis on interpretability and reliability to support clinical decision-making.

2. Introduction

Healthcare systems generate large volumes of structured patient data, including medical test results and demographic information. Traditional diagnosis methods rely heavily on physician expertise and manual analysis, which can be time-consuming and prone to human error. Machine learning provides an opportunity to analyze such data efficiently and uncover patterns that may not be immediately visible.

This project aims to design a scalable and interpretable heart disease prediction system that assists clinicians by providing data-driven insights while maintaining transparency and reliability.

3. Problem Statement

To design and implement a machine learning system that predicts the presence of heart disease in patients using structured clinical data, ensuring high recall, interpretability, and reproducibility.

4. Objectives

- To preprocess and standardize clinical patient data
- To train and compare multiple machine learning models
- To evaluate models using healthcare-relevant metrics
- To provide explainability for model predictions
- To design a professional layered system architecture
- To support clinical decision-making through predictive insights

5. Dataset Description

The dataset consists of medical and demographic attributes collected from patients undergoing cardiac evaluation.

Key Attributes:

- Age
- Sex
- Chest pain type (cp)

- Resting blood pressure (trestbps)
- Serum cholesterol (chol)
- Fasting blood sugar (fbs)
- Resting ECG results (restecg)
- Maximum heart rate achieved (thalach)
- Exercise-induced angina (exang)
- ST depression (oldpeak)
- Slope of ST segment (slope)
- Number of major vessels (ca)
- Thalassemia (thal)

Target Variable:

- 0 – No heart disease
- 1 – Presence of heart disease

6. System Architecture

The proposed system follows a layered machine learning architecture, ensuring modularity, scalability, and interpretability.

6.1 Data Source Layer

This layer contains raw clinical patient data collected from medical records and diagnostic tests. The data is stored in structured format (CSV) and serves as the input source for the system.

6.2 Data Management & Preprocessing Layer

This layer is responsible for:

- Handling missing values using statistical techniques
- Encoding categorical features
- Scaling numerical features
- Splitting data into training and testing sets

Its primary role is to ensure data quality and consistency.

6.3 Feature Engineering & Representation Layer

In this layer, clinically relevant features are selected and transformed into numerical feature vectors suitable for machine learning models. This step improves learning efficiency and model performance.

6.4 Machine Learning Model Layer

Multiple classification models are trained, including:

- Logistic Regression
- Random Forest
- Gradient Boosting

The best model is selected based on medical reliability metrics such as recall and ROC-AUC.

6.5 Evaluation & Explainability Layer

This layer evaluates model performance using:

- Accuracy
- Precision
- Recall
- F1-Score
- ROC-AUC
- Confusion Matrix

Model interpretability is achieved using:

- Feature importance
- Permutation importance
- Partial Dependence Plots (PDP)

This ensures transparency and clinical trust.

6.6 Model Management Layer

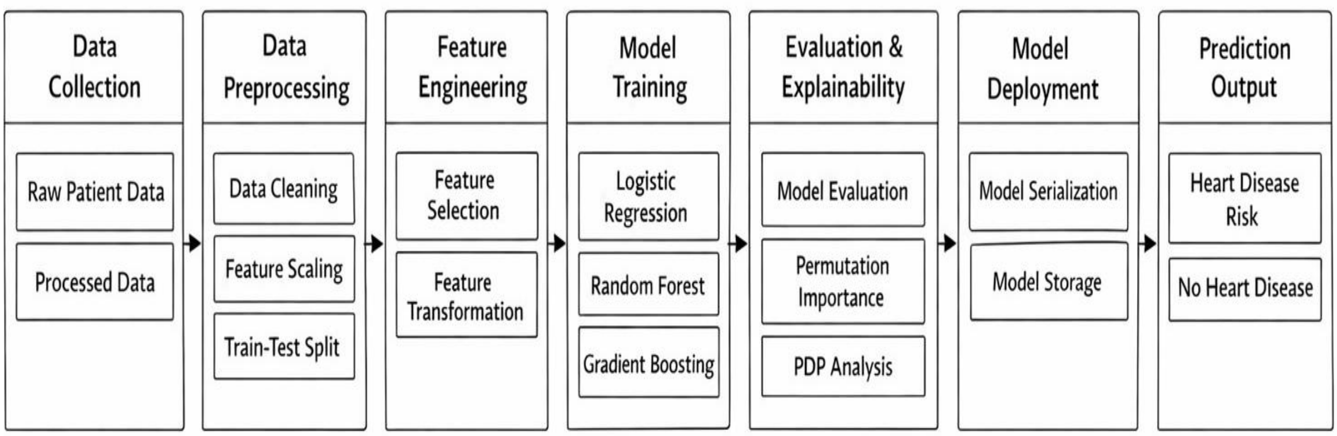
The selected model is serialized and stored for reuse and reproducibility. This layer supports version control and future deployment.

6.7 Decision Support & Output Layer

The final layer produces binary predictions indicating:

- Heart disease risk
- No heart disease

The output can be integrated into clinical decision support systems.



7. Methodology

1. Data collection and validation
2. Data preprocessing and feature scaling
3. Feature engineering
4. Model training and comparison
5. Model evaluation using medical metrics
6. Explainability and interpretation
7. Model persistence and output generation

8. Model Evaluation Strategy

In medical applications, recall is prioritized to minimize false negatives, as failing to detect heart disease can have severe consequences. Therefore, recall and ROC-AUC were the primary criteria for model selection.

9. Results and Discussion

The trained models demonstrated strong predictive performance, with ensemble models such as Random Forest and Gradient Boosting achieving high recall and ROC-AUC scores. Feature analysis revealed that chest pain type, age, cholesterol level, and maximum heart rate were among the most influential predictors of heart disease.

10. Conclusion

This project successfully demonstrates an end-to-end machine learning system for heart disease prediction using a professional layered architecture. The integration of preprocessing, model training, evaluation, and explainability ensures reliability, transparency, and practical applicability in healthcare environments.