Energy Saving Intelligent Smart Lights

Individual Project
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Introduction

Problem Statement

Traditional motion sensors often struggle to detect the presence of humans when they are still, resulting in unnecessary energy wastage due to lights remaining on or turning off incorrectly. This project addresses that issue by developing a smart lighting system capable of detecting human presence, even when motion is minimal or absent, to optimize energy efficiency.

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Objectives

The objective of this project is to develop an intelligent smart lighting system that can efficiently detect human presence, even when a person remains motionless, to significantly reduce energy consumption. By leveraging machine learning models such as Multi-Layer Perceptron (MLP) and Random Forest, the system classifies human presence based on sensor data, enabling more accurate and responsive lighting control. This will ensure that lights remain on only when necessary, providing a more energy-efficient solution compared to traditional motion sensor-based systems.

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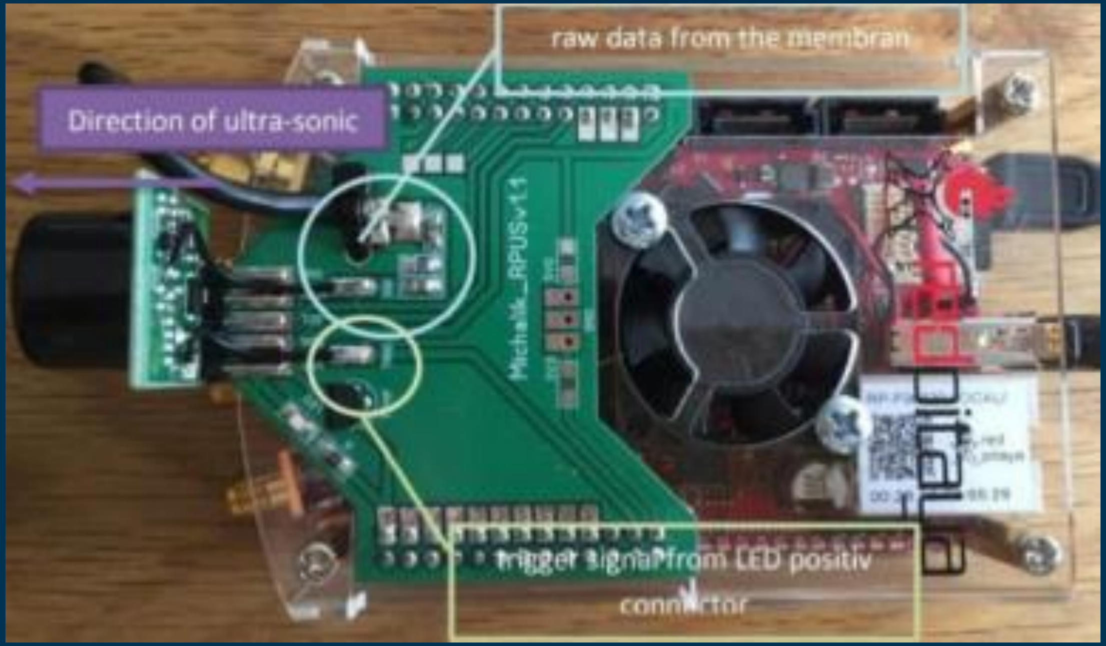
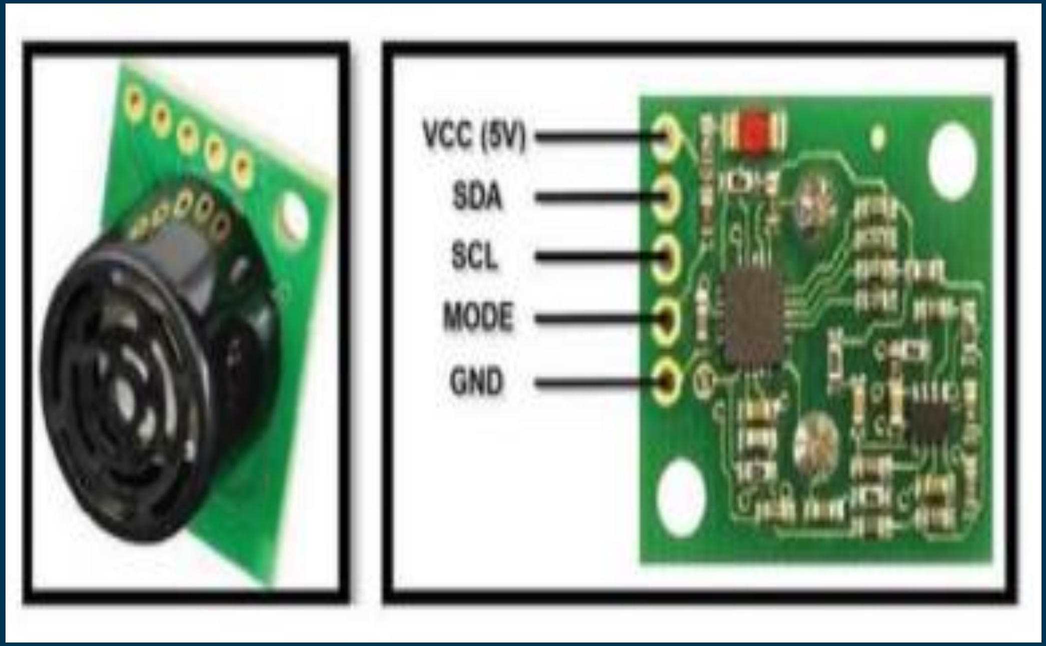
Methodology

Overview of Sensor Used



Red Pitaya - Controller



SFR02 - Ultrasonic Sensor

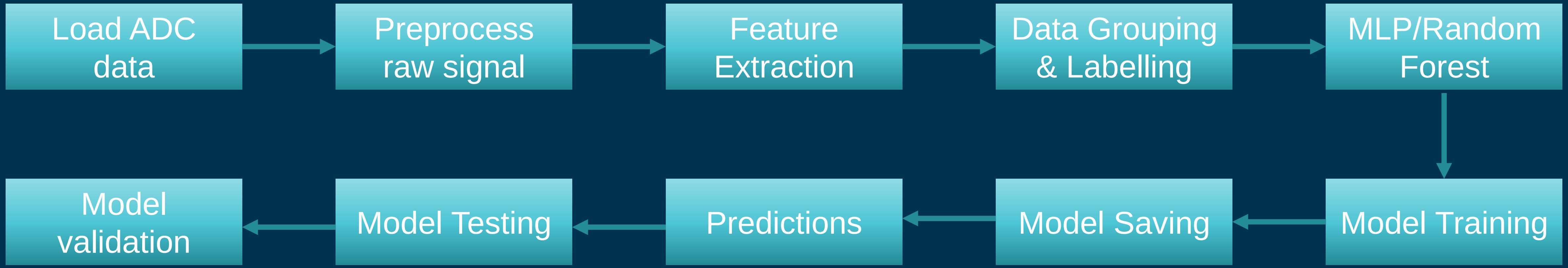
Overview of Setup

Static Object Setup

Dynamic Object Setup

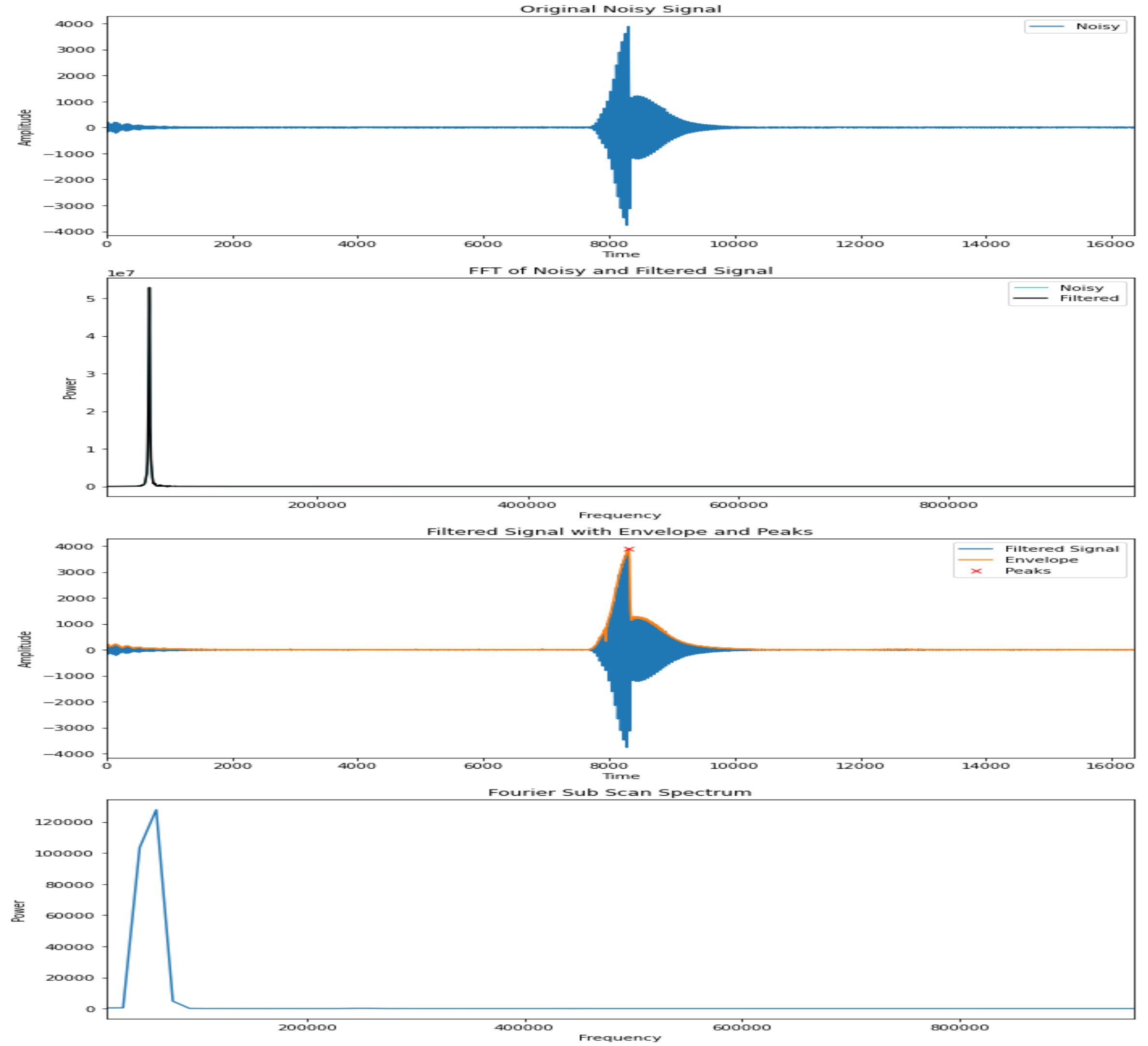
Implementation

Flowchart



Load ADC data
Preprocess raw signal
Feature Extraction
Data Grouping & Labelling
MLP/Random Forest
Model Training
Model Saving
Predictions
Model Testing
Model validation

Pre-Processing of Signal



The signal was filtered by using the following :

- Hilbert Transform
- Fast Fourier Transform

Features Extraction

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Time Based Features

- Time of flight
- First peak magnitude
- Rate of change of distance

Frequency based features:

- First peak frequency
- RMS
- Mean Frequency
- Max frequency
- Variance
- Energy of the signal

1. ML Model: Multilayers Perceptron(MLP)

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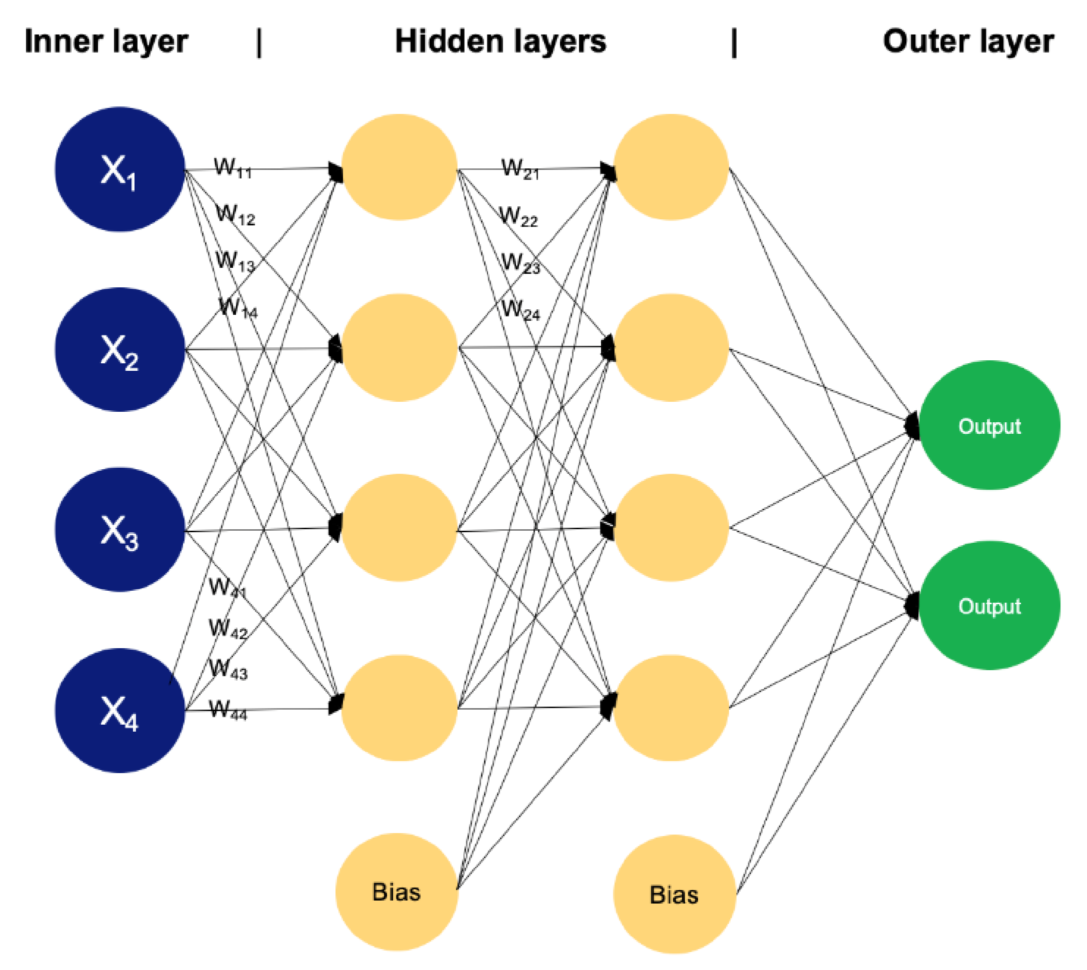
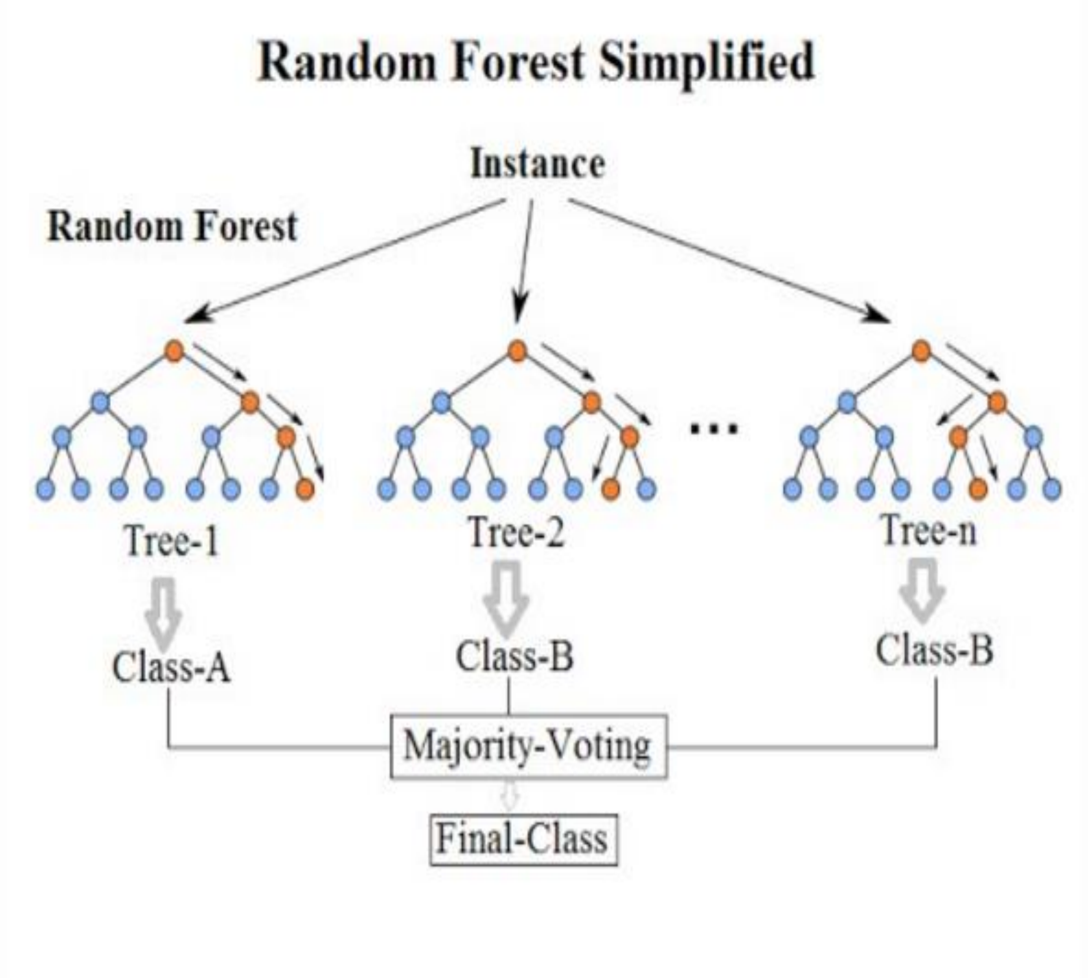
- MLP is a type of feedforward artificial neural network that consist of multiple layers of neurons(input, hidden, output)
- Each neuron uses activation functions like ReLU to capture non-linear relationships in data. (relationships between features derived from sensor data, such as motion and environmental variables)
- Features extracted are given as input and model is trained on labels(human / non human) and used back propagation and gradient descent to minimize loss.
- To optimize for better performance tuning of hyperparameters are done.



2. ML Model: Random Forest



- Random Forest is an ensemble learning method used for classification and regression. It builds multiple decision trees during training and combines their outputs for more accurate predictions.
- For classification tasks, each tree votes, and the most common class is selected as the final prediction. This robust combination of outputs results in improved performance.
- Random Forest excels in classifying complex datasets, making it ideal for distinguishing between subtle human movements and static objects.

Results

Pre-processing Signal

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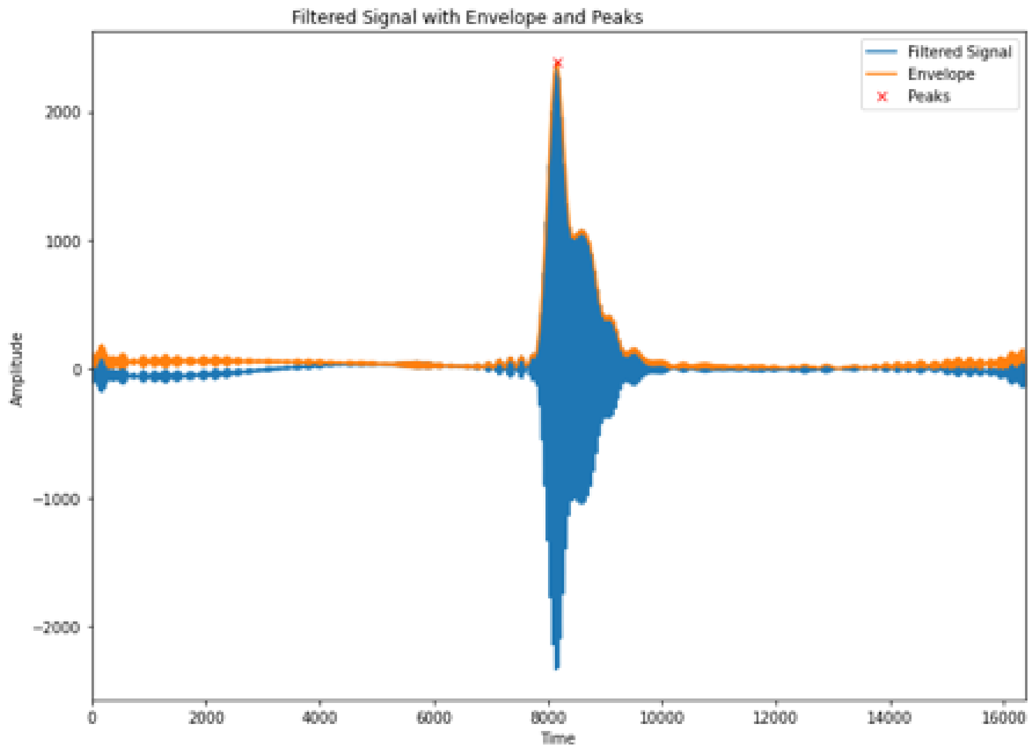

a) Static Object

b) Dynamic Object

1. MLP: Results for Static Object

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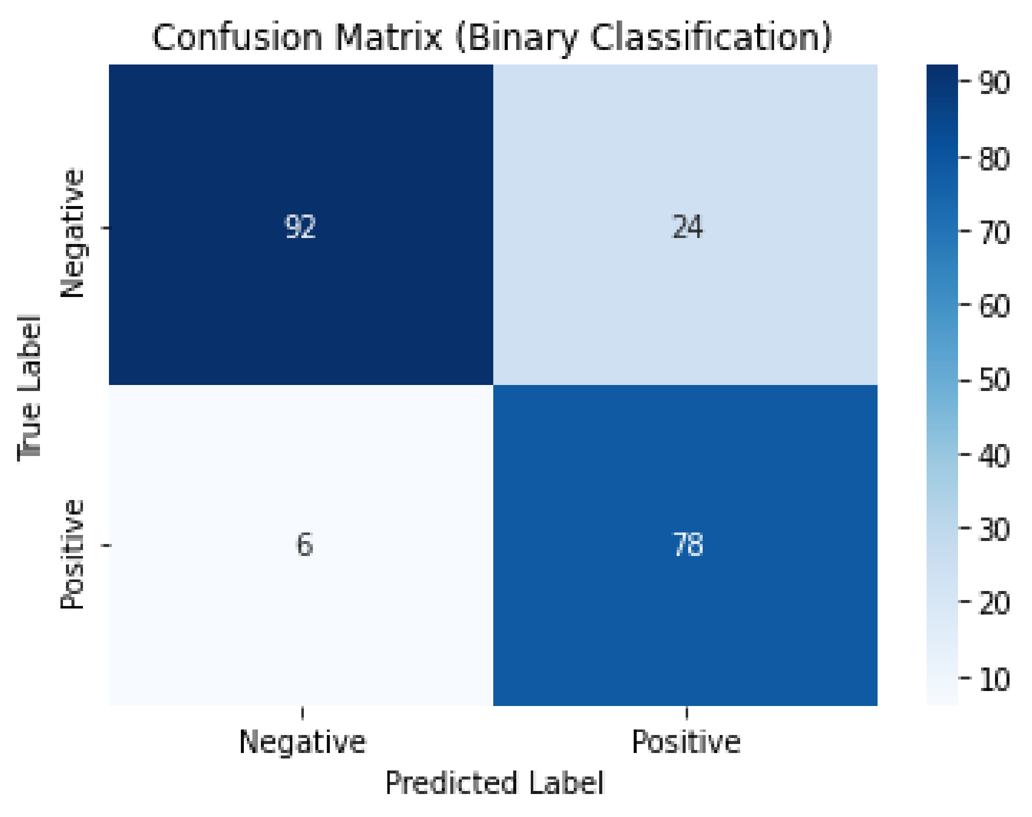
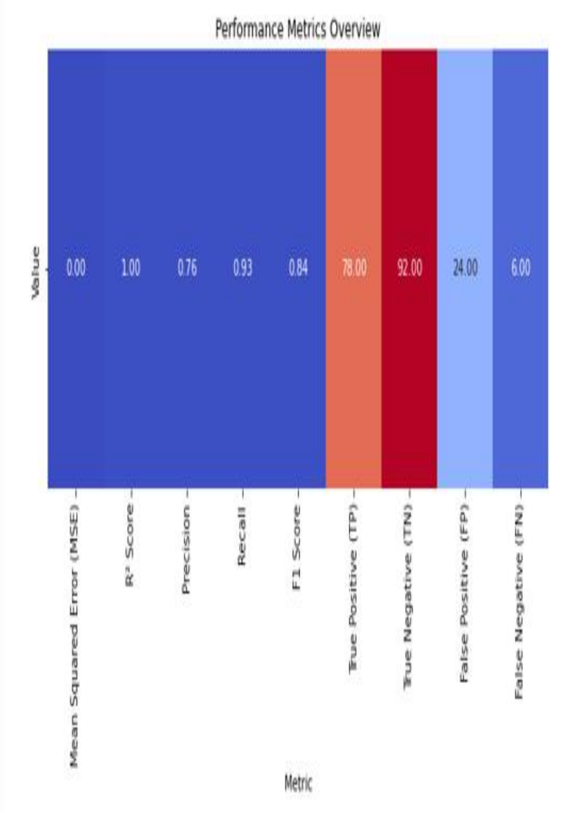


Performance Metrics:

	Metric	Value
0	Mean Squared Error (MSE)	0.001563
1	R² Score	0.998411
2	Precision	0.764706
3	Recall	0.928571
4	F1 Score	0.838710
5	True Positive (TP)	78.000000
6	True Negative (TN)	92.000000
7	False Positive (FP)	24.000000
8	False Negative (FN)	6.000000



1. MLP: Results for Dynamic Object (Person Walking)

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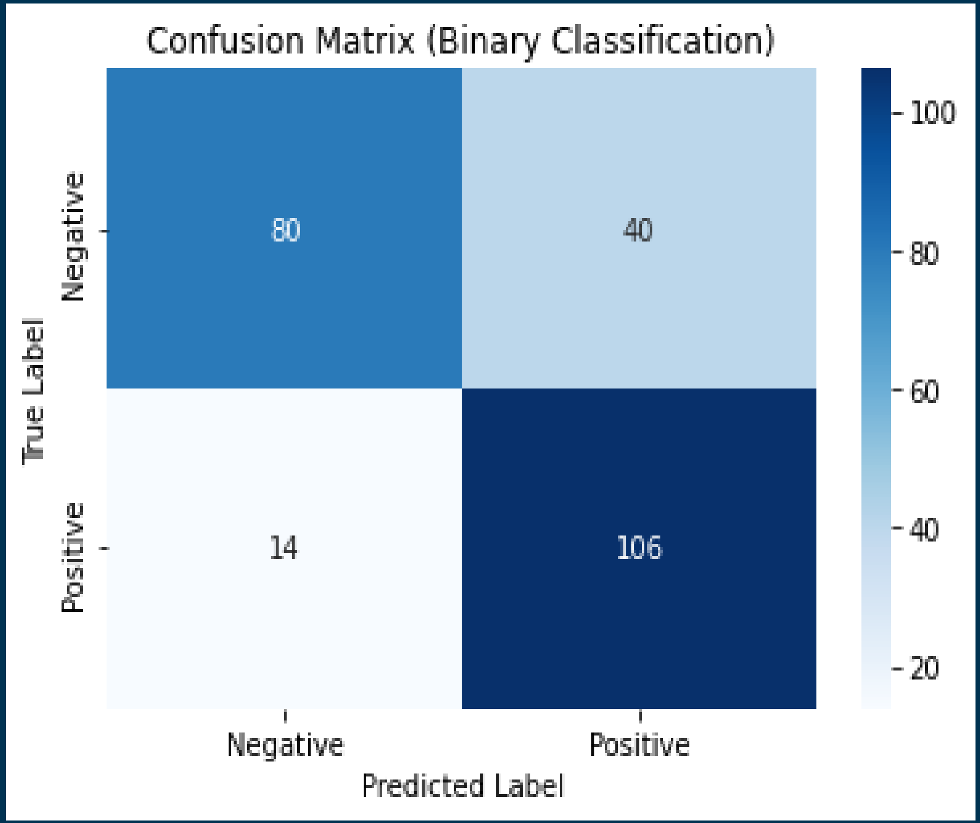
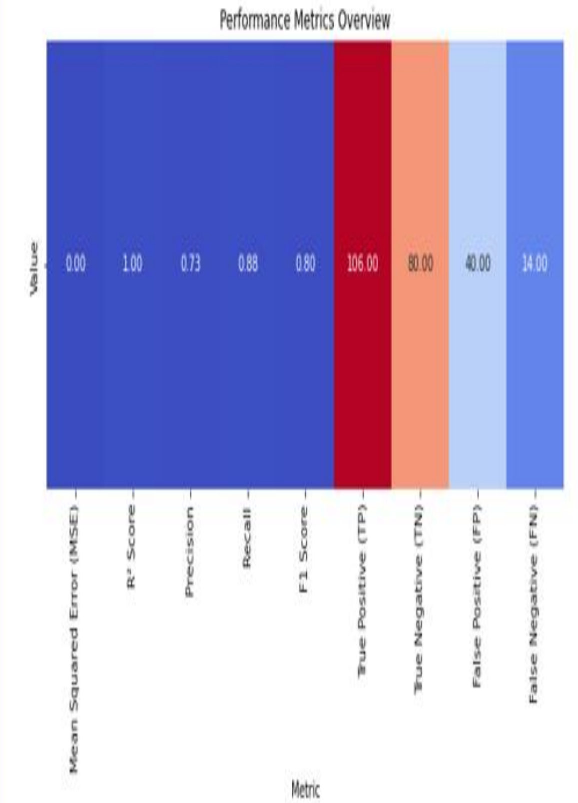


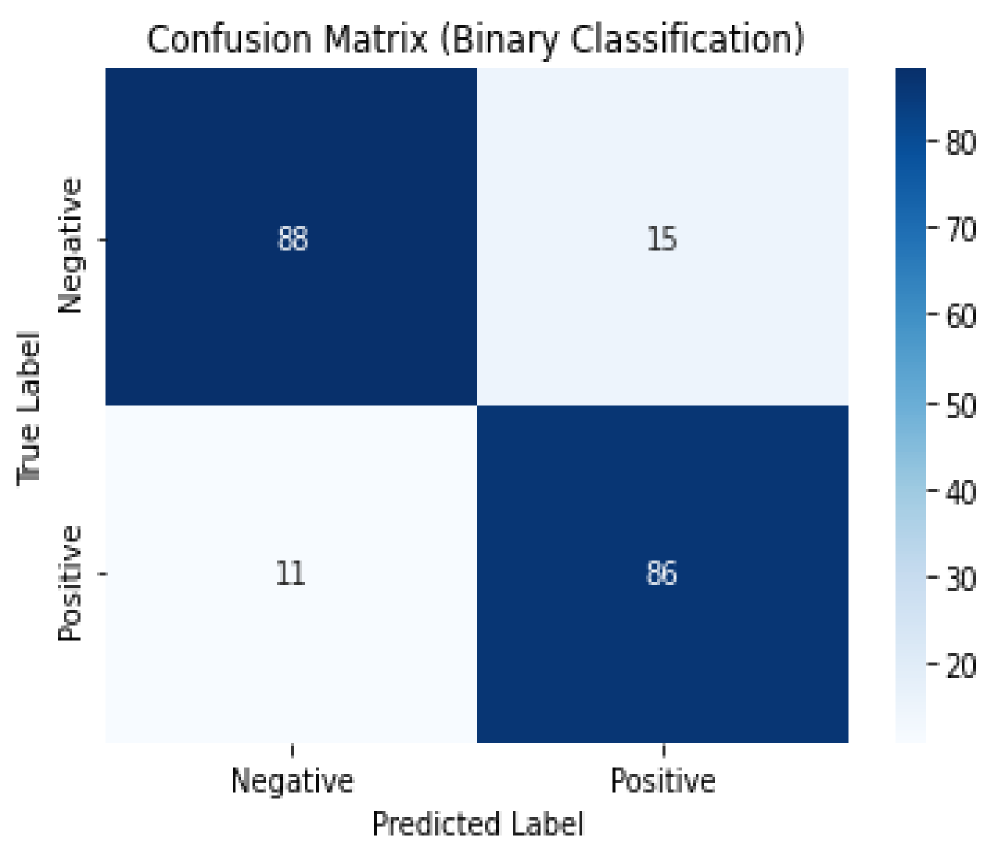
Mean Cross-Validated MSE: 0.9987

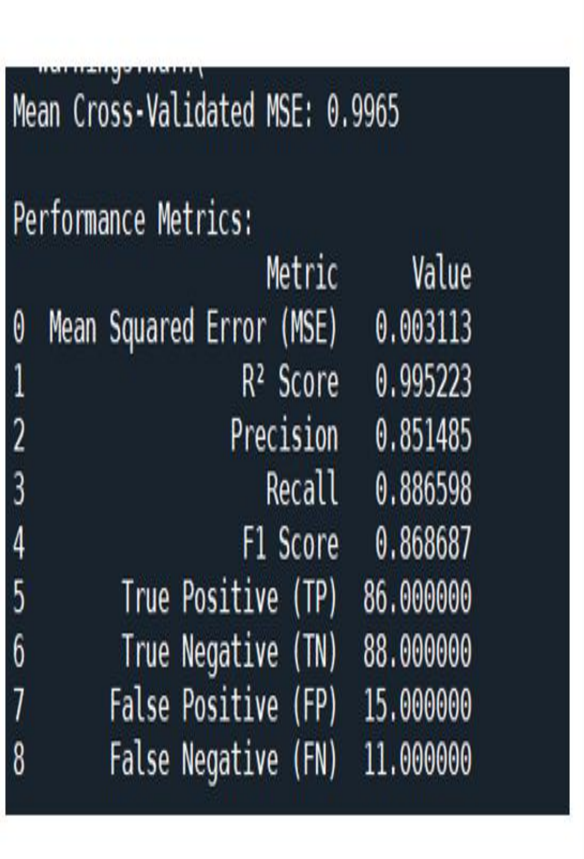
Performance Metrics:

	Metric	Value
0	Mean Squared Error (MSE)	0.000942
1	R^2 Score	0.998436
2	Precision	0.726027
3	Recall	0.883333
4	F1 Score	0.796992
5	True Positive (TP)	106.000000
6	True Negative (TN)	80.000000
7	False Positive (FP)	40.000000
8	False Negative (FN)	14.000000



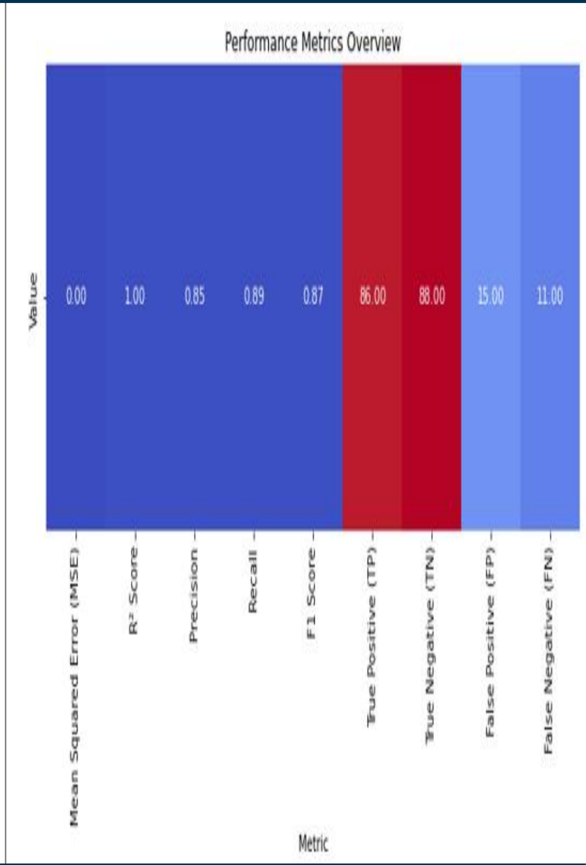
1. MLP: Results for Dynamic Object (Person Sitting)




Mean Cross-Validated MSE: 0.9965

Performance Metrics:

	Metric	Value
0	Mean Squared Error (MSE)	0.003113
1	R² Score	0.995223
2	Precision	0.851485
3	Recall	0.886598
4	F1 Score	0.868687
5	True Positive (TP)	86.000000
6	True Negative (TN)	88.000000
7	False Positive (FP)	15.000000
8	False Negative (FN)	11.000000



1. MLP: Results for Dynamic Object (Person Steady)

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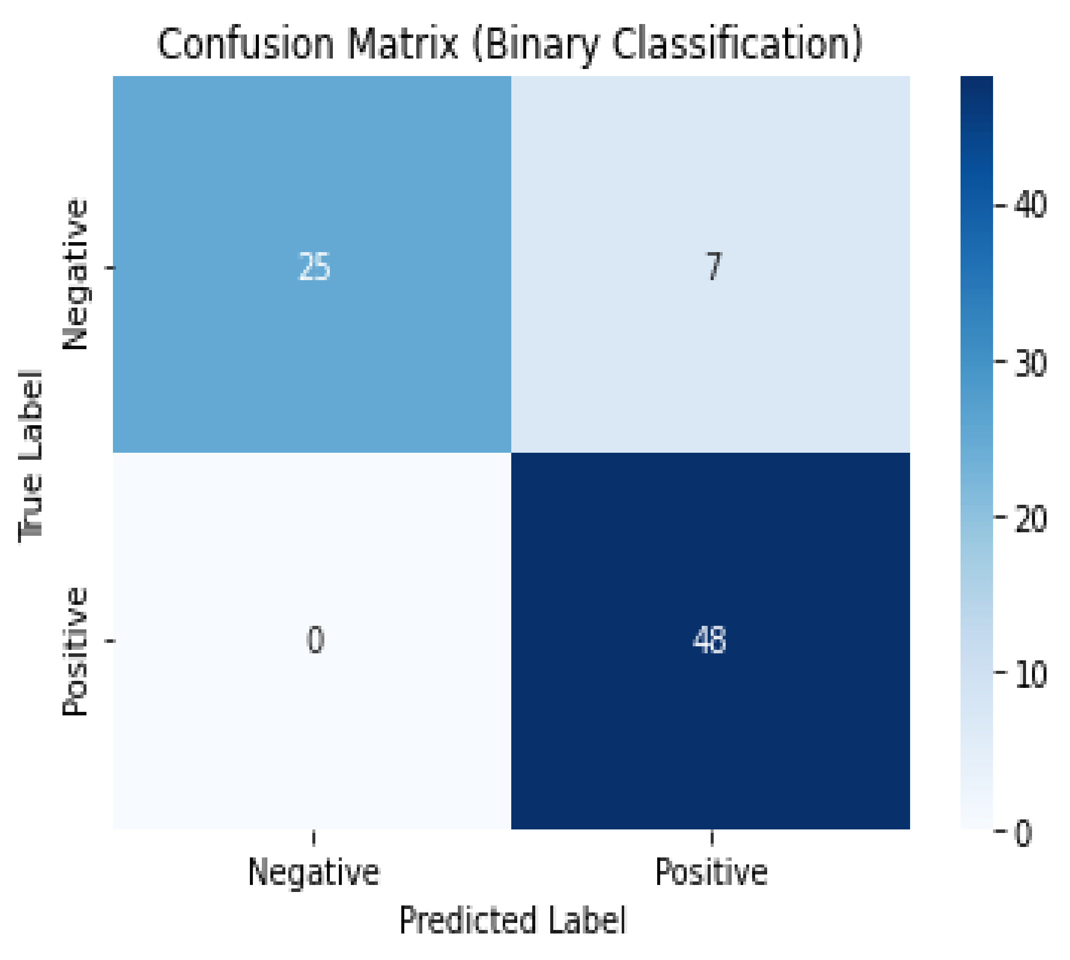
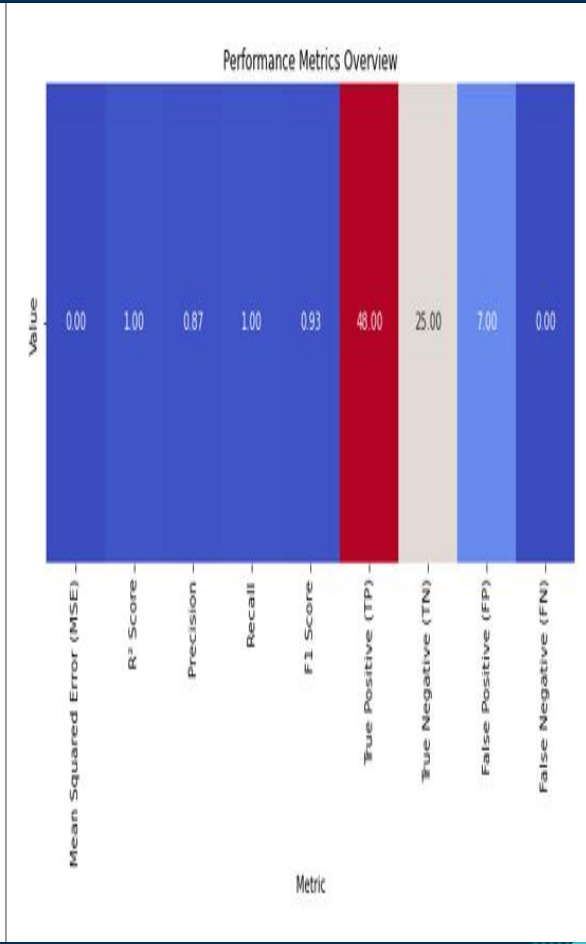


Mean Cross-Validated MSE: 0.9891

Performance Metrics:

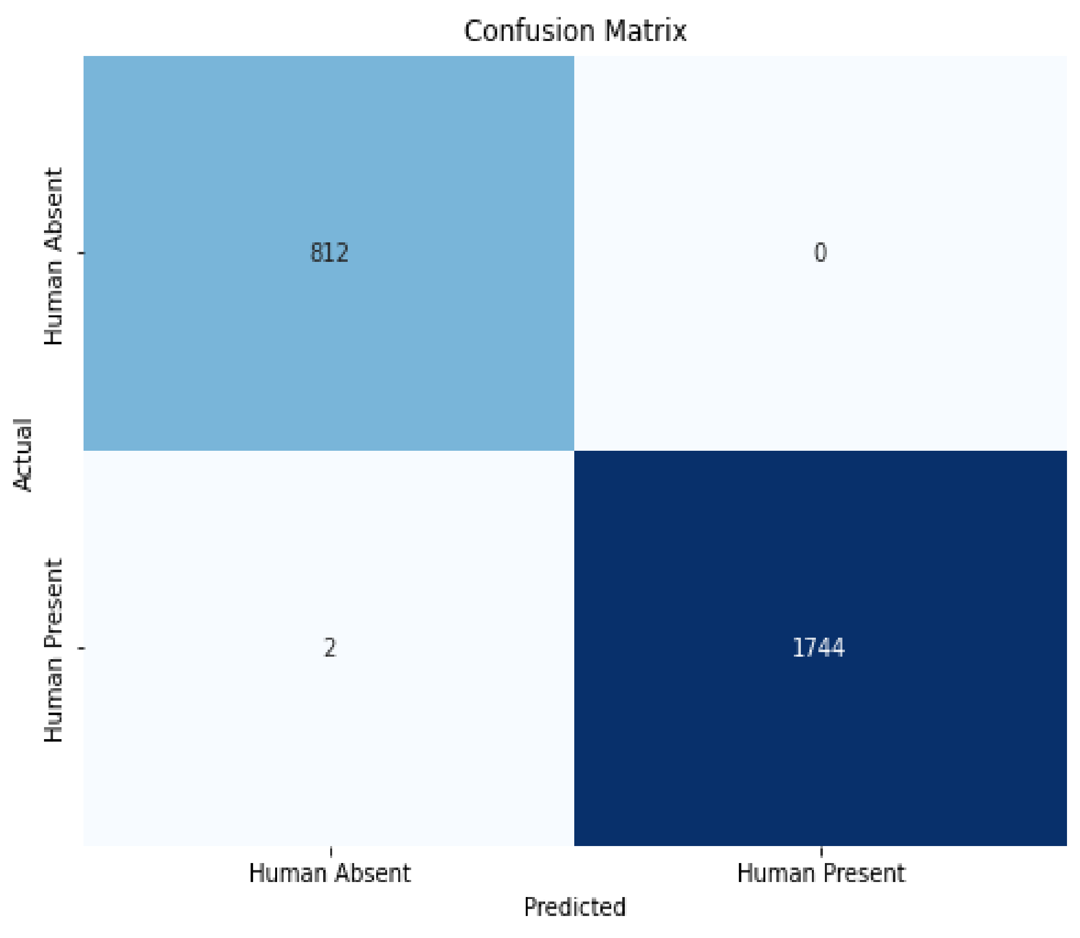
	Metric	Value
0	Mean Squared Error (MSE)	0.003830
1	R² Score	0.995328
2	Precision	0.872727
3	Recall	1.000000
4	F1 Score	0.932039
5	True Positive (TP)	48.000000
6	True Negative (TN)	25.000000
7	False Positive (FP)	7.000000
8	False Negative (FN)	0.000000



Analysis of MLP Results

- High Performance for Static Detection: Excels at detecting motionless humans, achieving perfect recall and a high F1 score.
- Challenges in Detecting Dynamic Movement: Faces limitations in precision when detecting activities like walking, resulting in more false positives.
- Good Balance Between Precision and Recall: Maintains a solid trade-off between precision and recall, ensuring effective detection in varied scenarios.
- Effective in Multiple Scenarios: Works well for detecting human presence in both static and dynamic environments, making it versatile.
- Potential for Reducing False Alarms: Needs improvement in minimizing false positives, especially during dynamic movements.
- Reliable for Smart Lighting Applications: Overall, the model is reliable but would benefit from further tuning to optimize performance in dynamic settings.

Random Forest : Results for Classification between Static and Dynamic Object.

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Fitting 5 folds for each of 24 candidates, totalling 120 fits
Accuracy: 0.9992
Classification Report:
              precision    recall  f1-score   support

           0       1.00      1.00      1.00       812
           1       1.00      1.00      1.00      1746

    accuracy                           1.00      2558
   macro avg       1.00      1.00      1.00      2558
weighted avg       1.00      1.00      1.00      2558

Confusion Matrix:
[[ 812    0]
 [   2 1744]]

Performance Metrics:
              precision    recall  f1-score      support
0              0.997543  1.000000  0.998770   812.000000
1              1.000000  0.998855  0.999427  1746.000000
accuracy       0.999218  0.999218  0.999218     0.999218
macro avg      0.998771  0.999427  0.999098  2558.000000
weighted avg   0.999220  0.999218  0.999218  2558.000000
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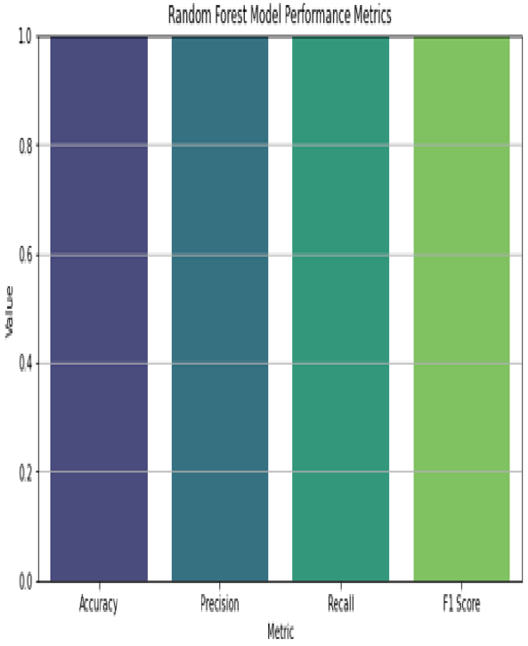

Analysis of Random Forest Results

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- Flawless Performance Across Scenarios: Achieves near-perfect precision, recall, and F1 scores in both static and dynamic environments.
- Highly Robust and Reliable: Demonstrates excellent performance in various conditions, ensuring accurate human presence detection.
- Superior Accuracy: Maintains near-perfect accuracy, making it highly reliable for real-time applications in smart lighting systems.
- Strong Generalization: Effectively handles diverse environmental setups, enhancing its ability to adapt to real-world scenarios.
- Ideal for Energy Efficiency: Accurate detection of human presence ensures optimal energy usage, reducing unnecessary lighting.
- Better candidate for Smart Lighting: Outperforms other models, proving to be the best choice for improving energy-efficient lighting control.

Conclusion

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Conclusion

- The project successfully aimed to enhance smart lighting by detecting human presence using ultrasonic sensors and machine learning models (MLP and Random Forest).
- Model Performance: While the MLP model is effective in detecting static human presence, it struggles with false positives in dynamic scenarios. Random Forest, however, achieves near-perfect accuracy across all environments.
- Energy Efficiency: Random Forest is the superior model, providing reliable human detection, minimizing false positives, and optimizing energy usage in smart lighting systems.

Thank You