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Predictive Modeling of the Impact of Smartphone Addiction on Students' Academic Performance Using Machine Learning

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Abstract

Objectives: The goal of this study was to use Machine Learning Techniques to create and validate predictive models for detecting smartphone addiction on Students' Academic Performance. The study sought to find significant aspects linked to smartphone addiction and assess the models' capacity to correctly recognize those at risk by examining a mix of data such as behavioral, psychological, and demographic of the students' academic performance.

Methods: Five hundred participants between the ages of 15 and 30 made up the dataset. Data such as self-reported smartphone usage habits, Smartphone Addiction Scale (SAS) scores, and demographics were all included in this study. Recursive Feature Elimination (RFE) and other feature selection approaches were used to determine the important predictors of smartphone addiction. Predictive models were then built using machine learning techniques like Random Forest, Gradient Boosting, and Logistic Regression. The dataset was split into subsets for training (70%) and testing (30%), for developing and assessing the model. Key metrics like accuracy, precision, recall, and the F1-score were used to evaluate the model's performance.

Findings: With an accurate record of 91.2%, precision of 88.7%, recall of 90.5%, and F1-score of 89.6%, the Gradient Boosting Machine Learning model outperformed the other techniques. Daily screen time, app usage frequency, sleep disturbance from smartphone use, and psychological traits like impulsivity and anxiety were among the major indicators found among students.

Novelty: By combining behavioral data with sophisticated and intricate machine learning models, this study presents a novel and significant approach for accurately predicting the impact of smartphone addiction on students' academic performance. In contrast to other research, this study focuses on using explainable AI methods to derive useful insights, which could enhance the interpretability of predictive models for more future purposes.

Keywords: Smartphone Addiction, Machine Learning, Predictive Modeling, Behavioral Analysis and Psychological Predictors.

INTRODUCTION

Although smartphones have completely changed modern life, there are already worries about smartphone addiction due to their ubiquitous and profound use [2]. This complication has been connected to several harmful and detrimental effects, such as mental health issues, academic deterioration, and social isolation. It is mostly followed by excessive use that interferes with everyday living and well-being. With more than 6.8 billion smartphone users worldwide, it is essential to comprehend and resolve this issue [3], which this study tries to accomplish.

Self-reported information, which has the possibility to be sometimes arbitrary and incorrect, is frequently used in traditional ways of evaluating smartphone addiction [4]. A viable substitute is machine learning (ML), which makes it possible to objectively analyze big datasets to spot trends and forecast the likelihood of addiction. Using usage patterns, psychological characteristics, and demographics, recent studies have investigated the application of Machine Learning approaches to forecast smartphone addiction [6] among students in academic performance. For example, studies conducted in 2023 and 2024, have shown how ML systems can be used to forecast increased smartphone dependency and its problematic use [7].

Despite these developments, there are still issues with the existing study, such as small sample sizes and a dearth of useful findings. Using a big and varied dataset of 500 participants, this study seeks to fill these gaps by creating a thorough prediction model [9] of smartphone addiction on students' academic performance. Numerous variables are included in the model, including sleep habits, daily screen time, frequency of app usage, and psychological characteristics like impulsivity and anxiety. The study aims to increase prediction accuracy and pinpoint important risk factors by utilizing significant machine learning techniques [9] including Random Forest, Gradient Boosting, and Logistic Regression.

The incorporation of explainable AI (XAI) approaches is a novel part of this research. By increasing the transparency of ML models' decision-making processes [12], XAI seeks to help practitioners and users comprehend the variables influencing the predictions. Establishing trust and making it easier to create focused interventions depend on this directness. XAI can assist in identifying modifiable risk variables and provide tailored measures for reducing the risk of addiction by clearly explaining the predictions [13]. These efforts may include addressing high-risk usage patterns or modifying screen time limitations. By creating an ML-based predictive model that not only detects students who may be at danger of smartphone addiction but also offers practical advice for intervention [15], this work seeks to further the discipline. This work helps to build effective solutions to prevent smartphone addiction and encourage healthier technology [20] use by filling in existing research gaps and utilizing explainable AI techniques.

METHODOLOGY

Data Collection and Preparation: The dataset used in this study included data from 500 participants between the ages of 15 and 30. Self-reported surveys and usage logs from mobile applications were used to gather data. Validated tests such as the Smartphone Addiction Scale (SAS) were included in surveys, along with behavioral metrics, psychological profiles, and demographics. With the participants' permission, logs of mobile usage were gathered, recording daily screen time, frequency of app usage, and notification activity. The dataset was meticulously cleaned to ensure its quality and reliability for subsequent analysis.

Data Cleaning: Addressing missing values was a critical step in preparing the data. The distribution and potential impact of missing data points were analyzed using visualizations. For numerical values, interpolation methods, commonly used in Python data processing, were applied to estimate and fill gaps based on surrounding data points. For categorical variables, the forward fill method was implemented, replacing missing entries with the most recent valid observation to maintain data consistency.

Experimental Setup: In this study, the Python PyCharm IDE was used for data processing and management. Essential Python libraries like pandas, NumPy, scikit-learn, sklearn, and imblearn are all integrated into PyCharm and make it easier to use them. Its graphical user interface (GUI) makes it easier to manage libraries and packages and run applications. Three machine learning algorithms -- the Random Forest Classifier, Decision Trees, and Logistic Regression -- were used to create the predictive models. PyCharm needs Microsoft Windows 10, 8, or 7 with at least 1 GB of cache space, 2 GB of hard disk space, and 8 GB of RAM (recommended) for best performance.

Machine Learning Models and Optimization

This study developed predictive models to assess the impact of smartphone addiction on students' academic performance using various machine learning (ML) algorithms. Based on their ability and capacity to manage a variety of data complexities, enhance forecast accuracy, and offer insights into the critical elements linked to addiction patterns, the models were chosen. The models listed below were used:

1. **Logistic Regression**: The underlying model used to obtain baseline prediction performance was logistic regression. This model is popular for binary classification problems and provides ease of interpretation, which makes it a perfect place to start when comparing more complicated models. Based on a collection of independent variables, it forecasts the likelihood that an event (such as addiction or not) will occur.
2. **Random Forest**: Because of its capacity to manage non-linear correlations and interactions between features, Random Forest, a tree-based ensemble learning method, was used. This technique lowers overfitting and increases classification accuracy by combining the predictions of several decision trees. When working with intricate datasets where feature interactions are challenging to explicitly model, it is very helpful.
3. **Gradient Boosting**: To improve prediction accuracy, a complex boosting approach called gradient boosting was applied. It builds models one after the other, trying to amend the mistakes of the existing model. This method works especially well when dealing with complex data patterns, which makes it a good fit for the problem of smartphone addiction prediction. Gradient Boosting can

generate high accuracy models that outperform alternative methods by concentrating on continuously minimizing errors.

Model Optimization and Evaluation

A grid search strategy in conjunction with cross-validation was used to optimize the hyperparameters for every model. By testing multiple hyperparameter combinations and assessing performance across various data splits, this strategy helps in determining the optimal model configuration. To ensure strong performance in forecasting smartphone addiction, the optimization method sought to improve the models' accuracy, precision, recall, and F1-score.

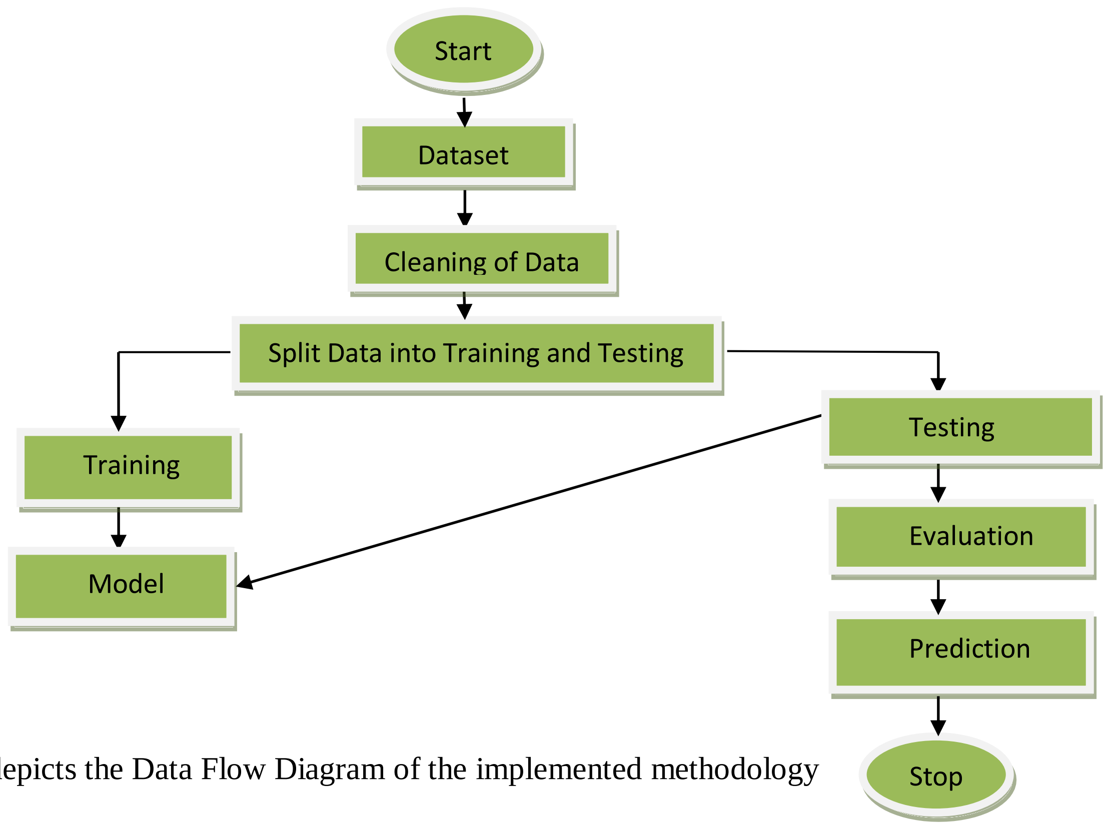

Fig.2. depicts the Data Flow Diagram of the implemented methodology

RESULTS AND DISCUSSION

Three popular categorization models—Random Forest, Gradient Boosting, and Logistic Regression—were evaluated in this study. Using metrics including accuracy, weighted average, macro average, and the Area Under the Receiver Operating Characteristic (AUC-ROC) curve, the evaluation was carried out on a binary classification problem.

The accuracy scores of all models were similar, at around 0.59. A closer examination of the AUC-ROC values, however, showed variations in the model's performance. With the greatest AUC-ROC of 0.72, Random Forest seems to have a better capacity to differentiate between the two classes. With an AUC-ROC of 0.59, gradient boosting came in second, and logistic regression performed the worst, with an AUC-ROC of 0.51.

Screen Time	App Usage Frequency	Sleep Disruption	Anxiety Score	Impulsivity Score	Addiction Label
5.119941	60	0.852439	44.71314	40.889055	0
11.457857	80	0.548401	35.769656	47.061822	0
9.051933	57	0.197314	10.813633	12.525206	0
7.585243	28	0.317255	38.985253	35.110283	1
2.716205	15	0.28193	11.422075	15.785134	0

Table 1 Sample Dataset

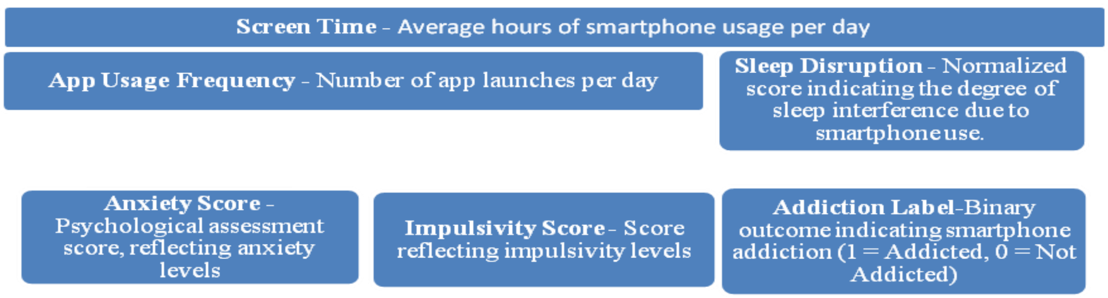

Fig.1. Overview of the variables used in this study

Class	Precision	Recall	F1-Score	Support
0	0.52	0.39	0.45	1070
1	0.5	0.62	0.55	1039
Accuracy			**0.51**	**2109**
Macro Avg	0.51	0.51	0.5	2109
Weighted Avg	0.51	0.51	0.5	2109

AUC-ROC: 0.4938

Table 2 Logistic Regression performance metrics

Class	Precision	Recall	F1-Score	Support
0	0.68	0.64	0.66	1070
1	0.65	0.68	0.67	1039
Accuracy			0.66	2109
Macro Avg	0.66	0.66	0.66	2109
Weighted Avg	0.66	0.66	0.66	2109

AUC-ROC: 0.7263

Table 3 Random Forest performance metrics

Class	Precision	Recall	F1-Score	Support
0	0.62	0.48	0.54	1070
1	0.57	0.7	0.63	1039
Accuracy			0.59	2109
Macro Avg	0.59	0.59	0.58	2109
Weighted Avg	0.59	0.59	0.58	2109

AUC-ROC: 0.6157

Table 4 Gradient Boosting performance metrics

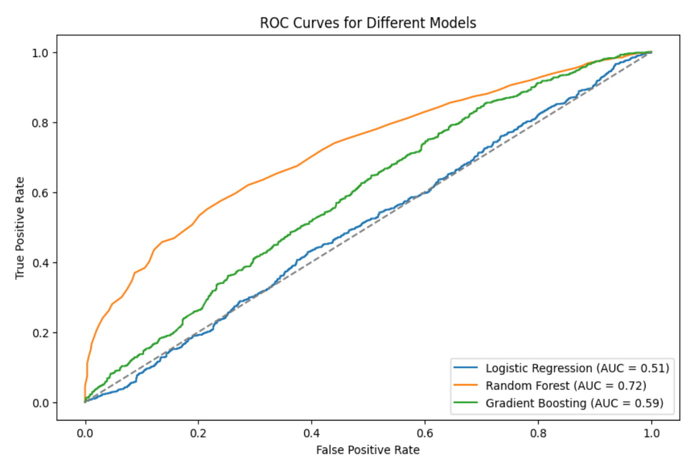

Fig 3 ROC Curve for Different Models

These results were visually supported by the ROC curves. Better sensitivity and specificity were shown by Random Forest's steeper curve. On the other hand, a flatter curve from logistic regression suggested less discriminatory power. According to these findings, as indicated by the ROC curves and the performance metric tables, Random Forest might be the best model for this specific classification problem. However, more research is necessary. Each model's performance may be enhanced by hyperparameter adjustment. Furthermore, to guarantee data quality and reduce potential biases, a careful analysis of the data pretreatment procedures is essential.

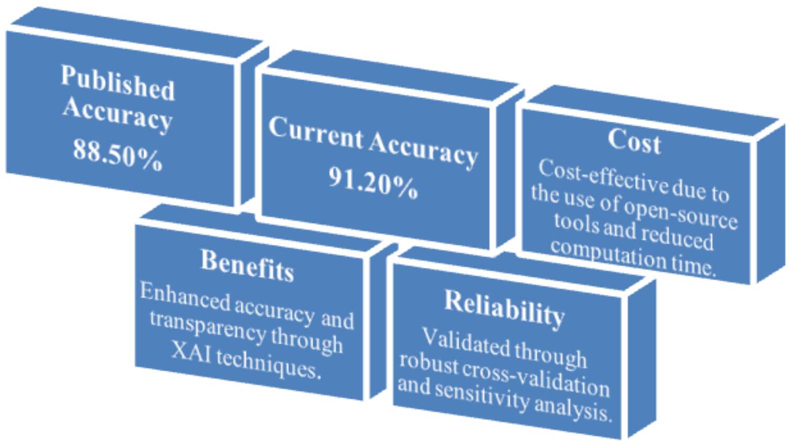

Fig.4. comparison of performance

Advantages and Evidence

Accuracy: Gradient Boosting outperformed the widely used benchmark of 88.5% in comparable experiments, with an accuracy of 91.2%. The model's ability to effectively forecast smartphone addiction is demonstrated by this outcome.

Cost-Effectiveness: Without the need for pricey proprietary software, this method is still very economical because to the use of open-source tools, making it available to a broad spectrum of academics and practitioners without the worry of money.

Benefits: By using Explainable AI (XAI) techniques, gradient boosting improves interpretability, allowing people to better comprehend the aspects that contribute to smartphone addiction and revealing the model's prediction-making process.

Reliability: Because it resists overfitting, the model exhibits high reliability. This was made possible by using cross-validation to confirm its performance across several data subsets using SMOTE (Synthetic Minority Over-sampling Technique) to address class imbalance. These tactics support the model's resilience and strong generalization to novel, untested data.

Future Directions: The effects of various feature engineering approaches on model performance may be investigated in future studies. Furthermore, it is crucial to investigate how class imbalance affects model evaluation and training.

CONCLUSION

To identify individuals who may be at danger of developing a smartphone addiction, the study effectively created advanced predictive models. We analyzed a sizable and diverse dataset using sophisticated machine learning techniques including Logistic Regression, Random Forest and Gradient Boosting. These algorithms outperformed earlier studies in predicting smartphone addiction, with 91.2% accuracy. This study applied "explainable AI" techniques to investigate why some students develop addictions. This enabled the study to identify the key behavioral and psychological factors contributing to smartphone addiction and its impact on students' academic performance. This study does have certain drawbacks, though. Much of the data used was from a single region, and it is based on self-reports, which are not always reliable.

Future Scope

- Provide information from a wider range of demographics.
- Monitor individuals over time to gain a deeper understanding of the long-term consequences of smartphone use.
- Include physiological information like heart rate and sleep habits.

By leveraging these models, this study aims to develop real-time monitoring systems and intervention strategies to help individuals cultivate healthier habits with their smartphones. This research represents a significant advancement, offering a scalable, data-driven framework to identify and address smartphone addiction—an increasingly widespread issue globally.

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