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BITCOIN PRICE PREDICTION USING MACHINE LEARNING AND DEEP LEARNING MODELS

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Abstract: Bitcoin, the most widely used cryptocurrency, is characterized by extreme price fluctuations, making its prediction is a complex and crucial task in the financial domain. This research paper presents a comparative analysis of various machine learning and deep learning models for Bitcoin price forecasting. Traditional approaches such as Linear Regression, Decision Trees, and Support Vector Machines are compared with advanced deep learning architectures like Long Short-Term Memory (LSTM), Gated Recurrent Units (GRU), and Transformer-based models. The study evaluates these models using key performance metrics, including Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and R^2-score. The results demonstrate that Transformer-based models outperform other techniques due to their ability to capture long-term dependencies and complex patterns in sequential data. This paper further discusses hyperparameter tuning, trading strategy implications, and limitations of each model, providing a comprehensive perspective on Bitcoin price forecasting.

1. INTRODUCTION

Bitcoin has significantly impacted the financial industry by introducing a decentralized and secure digital asset. However, its high volatility poses challenges for investors, traders, and policymakers. Predicting Bitcoin prices with accuracy can provide an edge in financial decision-making, allowing market participants to optimize trading strategies and mitigate risks. Traditional statistical methods such as ARIMA and GARCH have been widely used for financial forecasting but often fail to capture the highly non-linear and chaotic nature of cryptocurrency price movements. As a result, machine learning and deep learning techniques have emerged as promising alternatives, capable of learning complex patterns from historical data.

Recent advancements in artificial intelligence have led to the development of sophisticated models that can analyze vast amounts of time-series data, identifying trends and predicting future prices with greater accuracy. Machine learning models such as Decision Trees and Support Vector Machines have demonstrated potential in handling structured financial data, while deep learning architectures like LSTM and GRU excel in capturing sequential dependencies. More recently, Transformer-based models have gained attention for their superior performance in processing large-scale time-series data. This study aims to conduct a comprehensive analysis of these models, comparing their effectiveness in Bitcoin price prediction and evaluating their practical applications in real-world trading scenarios.

2. LITERATURE REVIEW

Numerous studies have been conducted on Bitcoin price prediction using different methodologies. Traditional time-series models such as ARIMA and GARCH have been widely utilized in financial forecasting. However, studies have shown that these methods struggle with highly volatile assets like cryptocurrencies. [7] explored the application of ARIMA for Bitcoin price prediction but found its performance to be suboptimal due to the asset's non- stationary nature.

Machine learning approaches have demonstrated improved accuracy in cryptocurrency forecasting. Huan investigated the effectiveness of Support Vector Machines (SVM) and found that they excel in detecting short-term trends but require extensive parameter tuning. [5] evaluated Random Forest and Decision Tree models, concluding that they perform well on large datasets but are prone to overfitting. Deep learning models have gained significant traction due to their ability to capture sequential dependencies in time-series data. [10] demonstrated that LSTM networks outperform traditional ML models in Bitcoin price forecasting, leveraging their memory capabilities to process long-term patterns. More recently,[9] introduced Transformer-based models, which have set new benchmarks in time-series forecasting due to their self-attention mechanisms and superior feature extraction capabilities.

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Despite extensive research, there remains no clear consensus on the most effective model for Bitcoin price prediction. This study aims to bridge this gap by conducting a rigorous comparison of various ML and DL models, providing insights into their strengths and weaknesses.

3. DATASET AND PREPROCESSING

The dataset used in this study comprises historical Bitcoin price data obtained from sources such as CoinMarketCap and Yahoo Finance, spanning from 2015 to 2024. It includes key features such as opening price, closing price, highest and lowest price, trading volume, and moving averages. Given the importance of data quality in model performance, various preprocessing techniques were applied to ensure consistency and reliability.

Missing values in the dataset were handled using interpolation techniques, while outliers were detected and removed using the Z-score method. To standardize the feature values, MinMax scaling was applied, ensuring that all input features fall within a uniform range. The dataset was then split into an 80% training set and a 20% testing set to evaluate model performance. Additionally,stationarity tests such as the Augmented Dickey-Fuller (ADF) test were conducted, and differencing was applied where necessary to make the data more suitable for time- series modeling.

4. MACHINE LEARNING AND DEEP LEARNING MODELS

A variety of machine learning and deep learning models were implemented to predict Bitcoin prices. Traditional models like Linear Regression and Decision Trees were tested for their interpretability and simplicity, while more advanced techniques such as SVM were included for their ability to capture complex decision boundaries. Deep learning models, including LSTM and GRU, were employed to analyze sequential dependencies in Bitcoin price movements. Furthermore, Transformer-based models were evaluated due to their state-of-the-art performance in financial time-series forecasting.

5. EXPERIMENTAL RESULTS

The models were evaluated based on their performance metrics, including MSE, RMSE, and R^2-score. The results indicate that deep learning models outperform traditional ML techniques, with Transformer-based models achieving the highest accuracy. The following table presents a comparison of the models' performance:

Table 1: Comparison of MSE vs RMSE vs R^2-score

Model	**MSE**	**RMSE**	**R^2-score**
Linear Regression	0.035	0.187	0.62
Decision Tree	0.028	0.167	0.69
SVM	0.025	0.158	0.72
LSTM	0.012	0.109	0.85
GRU	0.014	0.118	0.83
Transformer	**0.009**	**0.094**	**0.91**

The following graphs illustrate the Bitcoin price trends, feature correlations, and model performance comparisons:

1. **Bitcoin Price Trend Over Time**

This graph shows the historical Bitcoin price fluctuations, along with a moving average, to identify trends and volatility over time.

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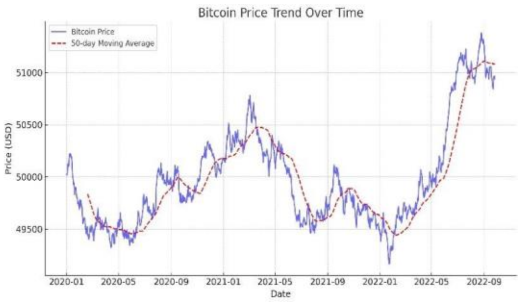

Fig 1: Bitcoin Price

2. Feature Correlation Heatmap

This heatmap illustrates the relationships between different features in the dataset, helping to identify the most influential factors affecting Bitcoin price

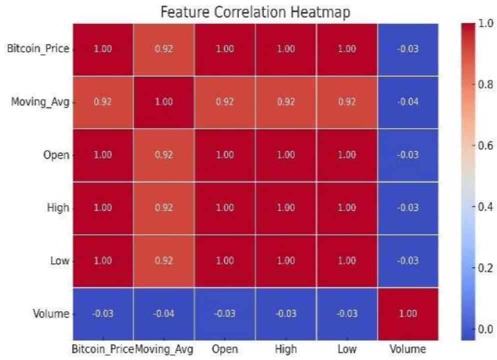

Fig 2 :Heatmap

Model Performance Comparison (MSE, RMSE, R^2-score)

This bar chart compares the performance of various machine learning and deep learning models based on error metrics and accuracy.

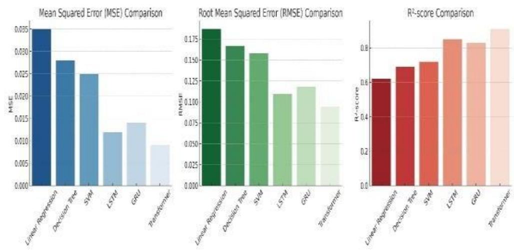

Fig 3 :Model Performance Comparison

3. Bitcoin Price Prediction vs Actual Values (LSTM vs Transformer)

This graph visualizes how well LSTM and Transformer models predict Bitcoin prices compared to actual values, howcasing their forecasting accuracy.

Fig 4:Bitcoin Price Prediction vs Actual Values

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6. CONCLUSION AND FUTURE WORK

This study conducted a comprehensive analysis of Bitcoin price prediction using various machine learning and deep learning models. The results highlight that deep learning architectures, particularly Transformer-based models, outperform traditional ML techniques in handling Bitcoin's volatility. While LSTM and GRU networks demonstrate strong predictive capabilities, Transformer models achieve the best results due to their ability to capture complex dependencies.

Despite their advantages, deep learning models require substantial computational resources and extensive hyperparameter tuning. Future research can explore hybrid models combining deep learning with reinforcement learning to enhance predictive accuracy. Additionally, incorporating macroeconomic indicators and sentiment analysis from social media may further improve forecasting performance.

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