Deep Learning for Financial Market: Evaluating LSTM, CNN, and RNN Models in Stock Price Analysis and Prediction

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***Abstract*—In this research, the historic data of stocks is analysed to check the trends of stock, sales volume, risks for investments and find the correlation between the stocks as well as utilized for predicting the closing prices of the stocks with the deep learning algorithms —Long Short-Term Memory (LSTM), Convolutional Neural Networks (CNN), and Recurrent Neural Networks (RNN). Using 12 years stock data of NVIDIA and Micron Technology, each deep learning model is trained to predict the closing prices of stocks. The models are evaluated using Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE) as evaluation metrics. Among three models, the result shows that RNN model outperforms with lowest error rate (MAE and RMSE values are 1.624 and 2.761) for NVIDIA stock and CNN also performs the best accuracy with lowest error rate (MAE and RMSE values are 1.909 and 2.601) for Micron Technology stock.**

***Index Terms*—Stock Prediction, LSTM, CNN, RNN**

I. Introduction

With the historical data and current stock market trends, advanced technologies such as machine learning, and deep learning are feasible to forecast the future stock prices and market volatility for investors [1]. Among them, the deep learning algorithms Long Short-Term Memory (LSTM), Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) are useful for predicting the stock prices [2]. Therefore, this research analyses some of the most trending technology related stocks of the year 2024, which are NVIDIA Corporation (NVDA), Micron Technology Inc. (MU), Microsoft Corporation (MSFT), Alphabet Inc. (GOOGL), Meta Platforms Inc. (META), and Apple Inc. (AAPL) as well as to implement the deep learning algorithms to predict the closing prices of NVIDIA Corporation (NVDA) and Micron Technology Inc. (MU) [3]. These specific companies from National Association of Securities Dealers Automated Quotations (NASDAQ) stock exchange are selected for this research due to their influence for artificial intelligence (AI), storage solution, cloud computing and innovative technology products [4]. Not only NVIDIA stock price significantly increases from $42.30 to $118.11 within a year for providing GPUs for the AI and deep learning applications but also the stock price of Micron Technology has risen from $63.11 to $139.01 between June 2023 to June 2024 for the demand of memory chips for AI and data centers [5],[6]. Moreover, technology giant companies such as Microsoft, Google, Meta and Apple are also remarkably noticed for the changes of their stock prices, according to the statistics of Yahoo Finance [7]-[10]. Nowadays, buying stock from reputational technology companies is one of the effective investment plans, therefore, not only experienced investors but also new investors are interested in buying these stocks from various platforms, such as official banks or digital bank including Revolut, or trading platform such as eToro and so on. Due to the history of stock markets, the stock prices can be volatile because of several factors, for instance, the coronavirus stock market crash is the most recent crash, which occurred in the early 2020 [11]. Therefore, there are different approaches of research experiments which forecast the future stock prices of well-known companies and their local companies using machine learning and deep learning techniques [2],[12-18]. There is still gap analysing the correlation of the prior mentioned stocks as well as prediction of the stocks such as NVIDIA and Micron Technology which are increasing the price of stocks especially in year of 2024 because of AI technology. By utilizing deep learning algorithms LSTM, CNN and RNN, the complex pattern of historical stock data will be assessed, and more accurate results will be predicted for investors [2]. Integrating these deep learning algorithms with vast historical stock data available through the Yahoo Finance, this research will do analysis and predictive accuracy of stock closing prices for long-termed and short-termed investors as well as for financial analysts to enable self-analysing to these specific stocks before buying them. This research paper comprises with five sections including introduction. The next section will discuss the research papers which utilize machine learning techniques such as Support Vector and Random Forest, and deep learning techniques LSTM, CNN and RNN for the stock price prediction. Subsequently, the methodology of this research will be explained which consists of the preparation and preprocessing of dataset, and

the deep learning algorithms and their architectures which are applied in this research and the evaluation metrics which are applied for model evaluation. After methodology, the detailed explanation of the evaluation results of the models which are trained and predicted. Moreover, the results of the models will be compared at this stage. After this section, the conclusion of the research and the proposed future work will be explained.

II. Related Work

The following eight research papers are reviewed to understand the different forms of research and methodology used in stock prediction with techniques. There are three sections which are comprised based on the use of machine learning, artificial neural network and deep learning techniques in stock market prediction.

A. Machine Learning and Artificial Neural Network

In [12], the significant machine learning models, Support Vector (SVR), Random Forest (RFR) and Linear Regression are applied for the prediction of stock prices using the historical data of the company to maximum the profits for the investors. Tesla dataset from Kaggle is used and 2956 days of stock data are predicted which are between 29-06-2010 and 24-03-2022. The dataset contains the open, high, close, low stock prices for each day. The results are evaluated with mean squared error (MSE), mean absolute error (MAE), root mean squared error (RMSE). Linear Regression can predict better than the other two models as its error rate is the lowest among the three models; MAE is 1.51, MSE is 15.21 and RMSE is 3.90. According to this research, it only focuses on implementation of the machine learning models but there is no fine-tuning for the models especially for SVR which has the highest error rate.

Through the use of machine learning approaches, [13] aims to leverage the power of technical analysis, company fundamentals, and financial news insights by identifying and providing precise predictions to enter or exit stock trading. Multinomial naïve Bayes machine learning model is applied for news headlines classification. Secondly, an artificial neural network with Keras library (sequential model) was created for technical analysis predictive model. After that, predictions of both analyses are combined into a logistic regression model. The dataset for new headlines contains stock market news from CNBC which includes high, low and close prices; apple stock data was retrieved from yahoo finance website which records are between February 2015 to January 2017 for technical analysis. The first analysis reached approximately 80% with text augmentation; the second achieved 88% accuracy for the training process. According to authors, the system accomplished the accuracy level of 92% in some cases but they do not explain specifically how it performs across different market conditions for long-term prediction.

B. Machine Learning and Deep Learning

The objective of [14] is developing a system for foresting stock trends with the use of various machine learning algorithms based on historical market data to predict the future prices. The authors employ algorithms which are Long-Short term memory (LSTM), linear regression, random forest and K-nearest neighbours. The historical data of Apple stock from Kaggle is used for this analysis. Subsequently, mean squared error is used for evaluation of each model; mean squared error of linear regression is 1.5417086, mean squared error of random forest is 0.316893179, 0.69425064 for KNN and 1.689194109 for LSTM. Among all of them, random forest achieves the best result. Moreover, the authors perform the sentiment analysis for 1000 tweets related to the Apple stock and this sentiment analysis result achieves 54% is positive and 46% is negative. It does not explain details how the data is pre-processed, how much the training and testing data are split and training process of each model although each algorithm is explained.

C. Deep Learning

It stated [15] that the financial market becomes volatile causes serious economic problems so the predicting the rising or falling stock in the financial markets in the future can be vital for investors. The deep learning models LSTM, Seq2seq, and WaveNet will be applied to predict stock of Taiwan. Taiwan stock data from 2007 to 2019 from Yahoo Finance API; 2007 to 2016 data are used as training data, and 2017 to 2019 data are used for testing. The top five stocks of Taiwan in 2017 which are (1) CATHAY HOLDINGS (2) Fubon Financial (3) CTBC HOLDINGS (4) E.S.F.H and (5) FFHC are used for evaluation. In the comparison of different deep learning methods with RMSE and correlation of actual and predicted prices, WaveNet outperforms the other two methods. According to authors, a better prediction model with more relevant parameters should be created.

In [16], a model with Recurrent Neural Network (RNN) and Long Short-Term Memory (LSTM) is built to predict the future closing prices of stock market values by assessing the improvement of accuracy with the number of epochs. From yahoo finance, the stock data of GOOGL and NKE from New York Stock Exchange NYSE are retrieved; GOOGL data is between 19 August 2004 and 19 December 2019, the data for NKE is extracted from 4 January 2010 to 19 December 2019. The epochs are in the range of 12, 25, 50 and 100 are applied during the training. For GOOGL, the loss decreased from 0.0011 at 12 epochs to 0.000497 at 100 epochs. The loss decreased from 0.0019 at 12 epochs to 0.000874 at 100 epochs for NKE. Both models evidenced improvement with increasing epochs, additionally, it consistently has the lower loss values with GOOGL when it is compared to NKE at all epochs. The constraint would be to find the best sets of data and number of epochs for training to increase the model prediction.

In [17], it builds a model which can guide the stock buyers when they invest in specific stocks so that the risk for investors will be lessened. Recurrent Neural Network (RNN) and Long-Short Term Memory (LSTM) are applied to the different datasets by exploring the accuracy and the number of epochs increment. According to the authors, the system will collect the information from user and apply machine learning

algorithms with the collected information and provide to user the optimal solution that which stock is safe to invest. The authors have collected the data from NSE stock exchange and the 20 years datasets of different companies such as TCS, Microsoft, Infosys and TATA are also collected from yahoo finance for the experimental study. For the evaluation, mean absolute percentage error (MAPE) is applied. The MAPE of Microsoft stock is 5.37, the MAPE of Infosys is 5.98, the MAPE of TCS is 3.06, and the MAPE of TATA stock is 4.14. In addition, this paper stated that one dataset has achieved almost 97% accuracy, but it is not explained the detail about it. As only one dataset got higher accuracy, the model has some limitations to perform to get high accuracy for all stated stocks although all are 20 years datasets.

A new system, SMP-DL [18] for predicting stock market prices using the deep learning is introduced, which has two steps; the first one is preprocessing data (DP) and the second step is stock price prediction (SP^2). In the second stage, bidirectional gated recurrent unit (BiGRU) is combined with long short-term memory (LSTM) to predict the stock market closing prices. For time series data, the authors extracted information of International Business Machines (IBM) stock from NYSE (New York Stock Exchange). The proposed model is evaluated with the metrices, mean absolute error (MAE), mean-squared error (MSE), root mean-squared error (RMSE) and R-squared error (R^2) with the results of 0.2099, 0.0831, 0.2883, and 0.9948. It could be occurred performance problem in future if more users are simultaneously using and querying the stock information on the smart trading platform (STP), and it can also impact for traders to sell or buy immediately when they cannot receive the important notification of stock information.

Multilayer Perceptron (MLP), Recurrent Neural Networks (RNN), Long Short-Term Memory (LSTM) and Convolutional Neural Network (CNN) are implemented [2] to predict the stock market price by using the day-wise closing price data of National Stock Exchange (NSE) of India and New York Stock Exchange (NYSE). From NSE, TATAMOTORS is used as the training dataset and Maruti, Axis bank and Hcl are used for testing. From NYSE, two active stocks are chosen, Bank of America (BAC) and Chesapeak Energy (CHK) which data are extracted from yahoo finance. Among the four models RNN, LSTM, CNN and MLP, CNN outperformed for the evaluation of the mean absolute percentage error (MAPE) of testing data of NSE; Maruti as 5.36, Hcl as 6.42, and Axis Bank as 7.94 with the historical data duration from 5th October 2007 to 30th June 2017. For predicting NYSE stocks with RNN, LSTM, CNN, and MLP, according to the author, CNN is observed as performing better than other models despite of being some of its region which shows less accuracy for predicted value as its MAPE for Bank of America is 5.31 and for Chesapeak Energy is 9.18. It does not explain the optimization and fine-tuning of its proposed model CNN for future use with other stocks.

Although the above studies achieved satisfied results for stock prediction, the specific study for Nvidia and Micron Technology which are the popular stocks of year 2024 [4] is still lacking so far. Therefore, this research will focus on not only analysing of the chosen six technology stocks to find the correlation between them but also predicting the closing price of NVIDIA and Micron Technology so that investors can utilize this research for their future investment.

III. Methodology

A. Data Preparation and Analysing

Using yfinance open source python library, stock data from Yahoo Finance will be extracted and used for stock data analysis and predictions. The stocks are chosen from the NASDAQ stock exchange, specifically from the Technology sector which are related to artificial intelligence, storage and cloud computing technologies. Stock information of NVIDIA (NVDA), Micron Technology (MU), Microsoft (MSFT), Google (GOOGL), Meta (META) and Apple (APPL) will be retrieved and the details of the attributes of each stock are explained in TABLE I. The historic data of these six stocks will be used for analysis and plotting. For model training and testing, NVIDIA and Micron Technology stock price data are chosen. The data range which will be extracted starts from 1st August 2012 to 1st August 2024 for analysing, training and testing models. The data is split into 80% for training and 20% for testing.

Since the stock market open only weekdays, business day (weekday) data is filtered using pandas library. Moreover, the stated stock are from the US stock market so, the stock market related to these stocks will be closed on the US holidays. Therefore, forward fill and backward fill functions are applied for holidays which are happened on weekdays to bring the most recent known value forward to fill in any missing values, and to carry the next known value backward to fill in any remaining missing values. After that, all data are combined into one dataset to proceed data analytics.

The data of visualized to understand and present market and the closing price trend of each stock, sales volume of each stock Figure1, checking risk and expected return of each stock Figure4, as well as finding correlation between NVIDIA and Micron Technology Figure 2 and also finding the correlation between mentioned six stocks which is shown in Figure 3. By doing so, the associated stocks can be identified to buy or sell when a particular stock price is increased or decreased than usual.

B. Models Selection and Architectures

In this research project, there are three deep learning algorithms, Short-Term Memory networks (LSTM), Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) which are utilized to build the stock closing price prediction models.

1) Long Short-Term Memory (LSTM) : The LSTM algorithm, a part of deep learning, is based on feed forward neural network model which can manage both entire sequences of data and single data points [17]. LSTM is a kind of gated RNN and LSTM became a significant model in several applications such as speech recognition, image captioning,

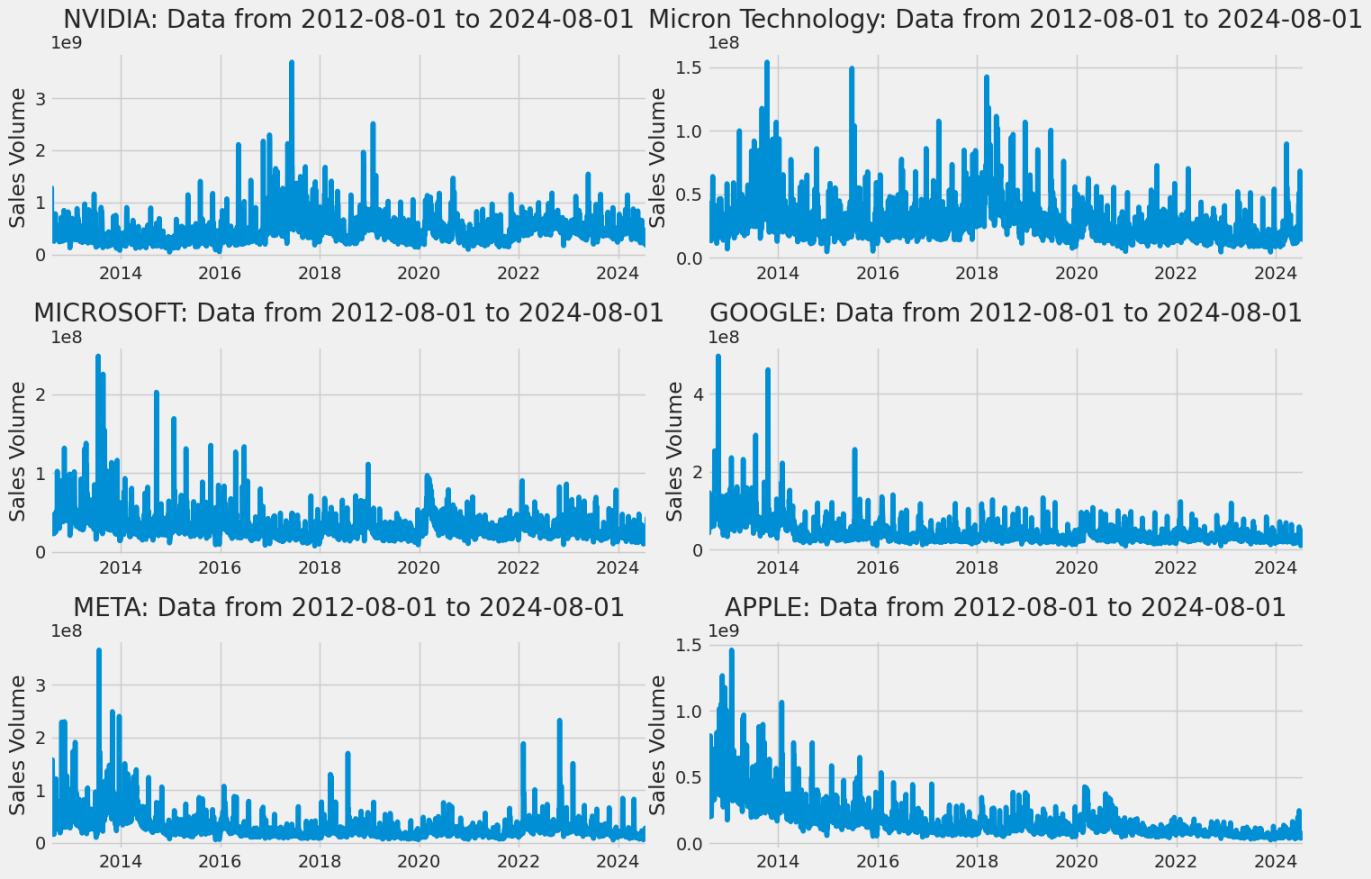

Fig. 1. Sales Volume Analysis of Stocks

TABLE I
DESCRIPTION OF ATTRIBUTES

Attribute	Description
Open	The stock price at the start of each trading day
High	The highest stock price which reaches during each trading day
Low	The lowest stock price which reaches during each trading day
Close	The stock price at the end of each trading day
Adj Close	The closing price, adjusted for all applicable splits and dividend distribution
Volume	The total number of shares traded during each trading day
Company_name	The name of the company, associated with the stock ticker, e.g. "GOOGL" is the ticker symbol for Alphabet Inc. (Google).

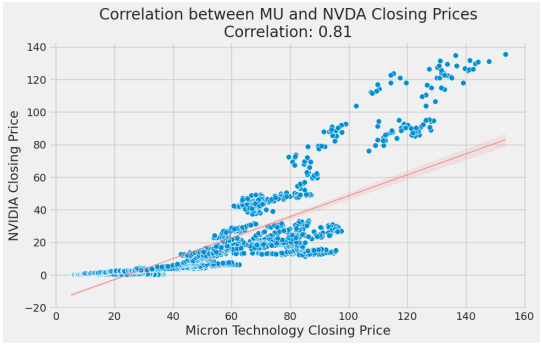

Fig. 2. Correlation between NVIDIA and Micron Technology

etc. due to the ability of keeping the long-term dependencies [19]. By doing so, LSTM is able to catch historical data and use it for prediction in future, therefore, stock market analysis and prediction is suitable for implementing the LSTM algorithm [16]. LSTM is built with the following architecture for predicting stocks.

- Input layer: The LSTM model accepts the input sequences of past stock prices with a shape of (the size of training data, the number of times to feed in the LSTM model, and the number of columns of each sample).
- LSTM layers: The first LSTM layer has 128 units and is configured to return sequences, passing the full sequence of outputs to the next layer. Then, A dropout layer with 20% to reduce overfitting. Subsequently, the second layer of LSTM is with 64 unit and it also returns sequences and followed by another dropout layer with 20%. The LSTM's third layer has 32 units which outputs only the last step in the sequence.
- The dense layer is with 25 neurones and ReLU activation

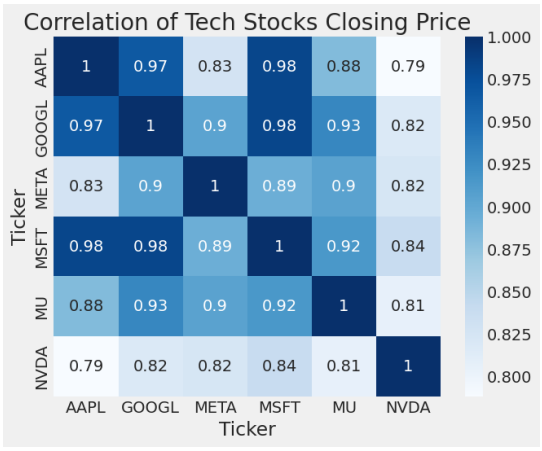

Fig. 3. Correlation between the closing prices of stocks

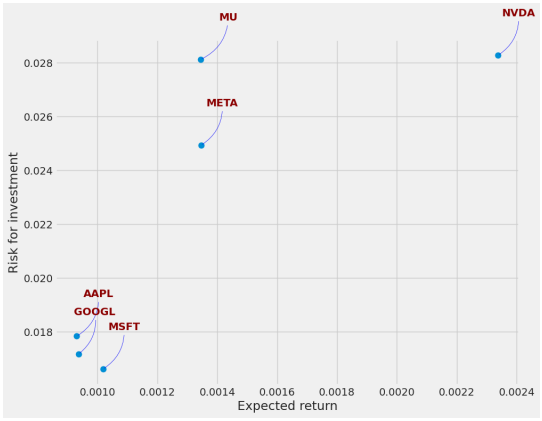

Fig. 4. Expected Return Vs Risk for Investment with Tickers

function is applied to process the output of the LSTM layers. The final layer, dense layer outputs a single value which is the predicted stock price.

2) Convolutional Neural Network (CNN) : CNN, the feed-forward neural network, includes input layers, hidden layers and output layers, moreover, the input of the convolution layer is the output of previous layer [20]. Unlike traditional neural network architecture, CNN has distinct features, pooling layers, full connection layers, more hidden layers and so on. Because of having many hidden layers, CNN is capable of extracting higher features and recognizing from input. Generally, CNN is popular for computer vision tasks such as image classification and face recognition [20]. Moreover, CNN is able to solve the prediction problem or other financial predictions with a satisfactory result [20],[21]. Therefore, CNN is one of chosen algorithms to train the stock market price prediction and comparing with LSTM and RNN. CNN is designed with the following architecture for predicting stocks.

- Input layer: The input layer of CNN model is the sequence of the past stock prices which are the size of training data, the number of times to feed in the model, and the number of columns of each sample.
- First convolutional layer: It has 64 convolutional filters are applied with the Kernel size setting as 3 which allows the model to extract features. After that, ReLU activation function is applied for non-linearity and it helps the model to learn complex patterns in data.
- Max Pooling Layer: This layer is utilized after the first convolutional layer to down-sample and reduce the dimensionality, by doing this which can help to extract the most relevant features as well as control overfitting.
- Second Convolutional layer: In this convolutional layer, 32 filters are applied to the pooled output from the prior layer. A smaller kernel size 1 is used and ReLU activation is used, same as the first convolutional layer.
- Flattening layer: The output of the convolutional layers is flattened into a single vector so that the dense layers are able to process it.
- Dense layers: The dense layer is with 25 neurons and it is with ReLU activation function to process the flattened output. The final dense layer consists of a single neuron which is the output of the predicted closing price of stocks.

3) Recurrent Neural Network (RNN): The RNN, one of the important models in deep learning, can be utilized for temporal cases [17]. It is specialized for processing time-series data or sequential data in which the obtained output result will be the feedback for another input at every single step [19]. Such a process can be described as a recurring process and so its architecture is also named as recurring neural network [19]. RNN models are popularly used for language modeling applications such as text classification, image-to-text, etc [19]. Since RNN is useful for time-series data [22], RNN is chosen for this stock market price research to predict for the future price of stocks after historical data of stock has been extracted [17],[19]. In RNN, the following architecture is built for predicting stock prices.

- Input layer : Same as prior models, RNN also comprises the sequences of past stocks prices
- First layer: It has 128 units which assists to capture the temporal dependencies of the data and the output of the layer is allowed to pass as a sequences to the next layer with the configuration as ”return_sequences=True”.
- Second layer: The second RNN layer use 64 units to process the sequence of data. As the configuration of ”return_sequences=False”, the only last output of the sequence will be passed to the next layer which is making into the single output.
- Dropout layer: 20% of dropout layer is added after first and second RNN layers. This layer will prevent the overfitting issue by setting 20% randomly as zero to RNN units during each iteration.
- Dense layer: This layer has a single neuron unit with linear activation function and this layer will generate the final prediction of closing price of stocks.

LSTM, CNN and RNN models are compiled using the optimizer ”Adam” and Mean Squared Error(MSE) is utilized

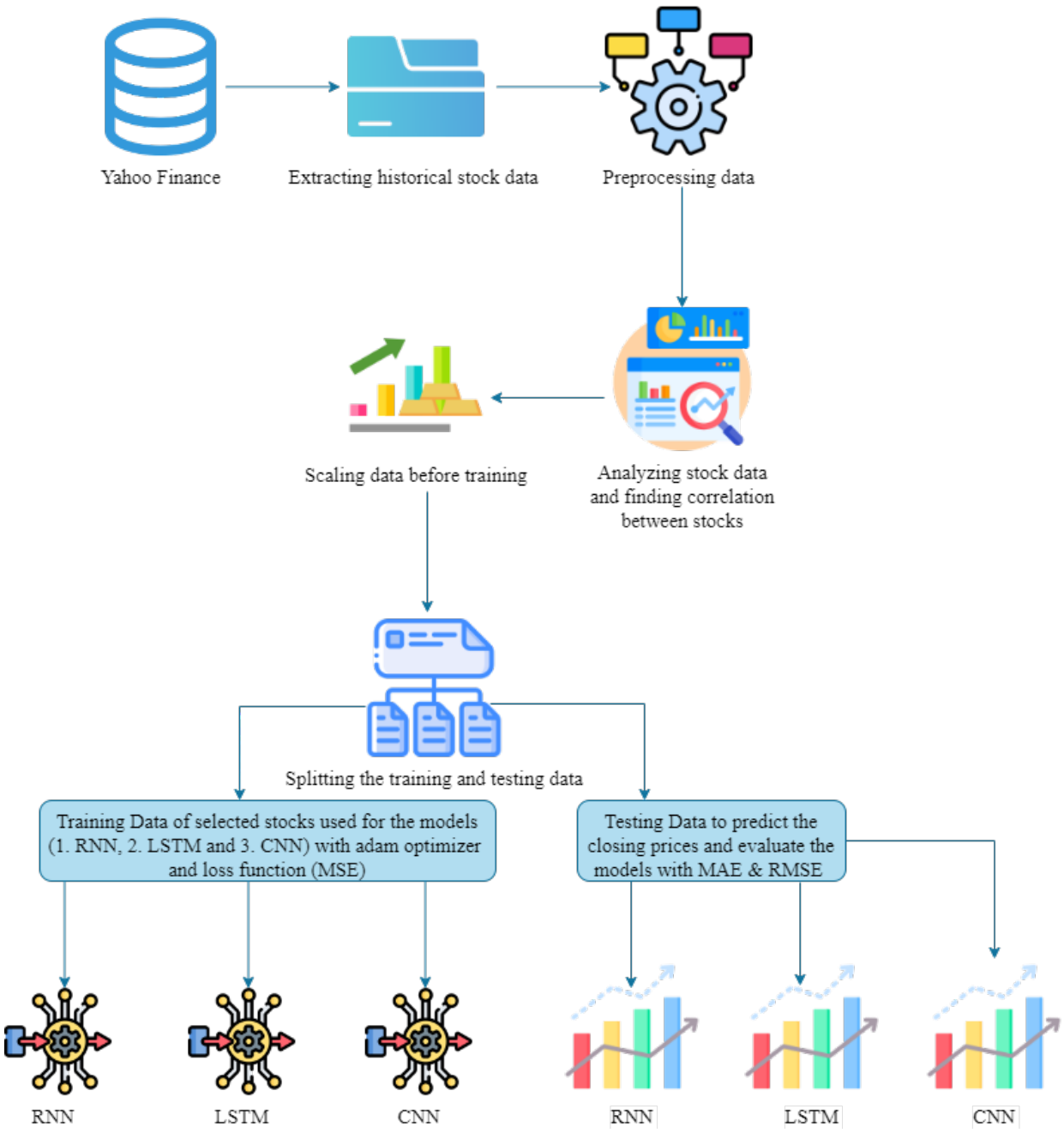

Fig. 5. Methodology for analysing stock data and predicting closing prices of stocks with LSTM, CNN and RNN models

as a loss function during training so that the prediction error can be lessen and minimized.

C. Evaluation Metrics

1) Mean Absolute Error (MAE): Mean Absolute Error (MAE) [23] is a popular metric for assessing forecasting or predicting accuracy. It measures the average absolute difference between the values that are expected or predicted and the values that actually occurred. The better accuracy is indicated with the lower MAE value. It offers a clear indicator of forecast accuracy, and is simple to interpret.

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

2) Root Mean Squared Error (RMSE) : Root Mean Squared Error (RMSE) [23] is useful for measuring the difference between values that have actually existed and the values which are predicted by a model. By using RMSE, the data dispersion around zero can be calculated. In general, if the model generates a smaller value, it means that the model has

predicted more accurately. RMSE will be used for evaluating while the trained models are predicting with testing data.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=0}^{n}(y_i - \hat{y}_i)^2}{n}} \quad (1)$$

IV. Evaluation Results

This section will mainly discuss the experiments of training the LSTM, CNN and RNN for predicting NVIDIA and Micron Technology stocks,and evaluate and compare their results. Before discussing the result of the models, the platform specification which is used during the experiments as well as the libraries which are utilized for this training will be presented.

A. Platform Specification

Platform : Google Colab Runtime type : Python 3 Hardware accelerator : T4 GPU Storage : Google Drive

B. Libraries and APIs

1) For preprocessing and visualizing data:

- yfinance
- pandas (pandas_datareader, ffill, bfill, freq (business day)
- numpy
- matplotlib
- seaborn
- sklearn (preprocessing)

2) For training and evaluating:

- keras.models (Sequential), keras.layers (Dense, LSTM, Dropout), keras.optimizers(Adam), keras.callbacks (EarlyStopping, ReduceLROnPlateau)
- tensorflow, tensorflow.keras.models (Sequential), tensorflow.keras.layers (Conv1D, MaxPooling1D, Flatten, Dense), tensorflow.keras.layers (SimpleRNN, Dense, Dropout)

C. Configurations for Models(LSTM,CNN,RNN)

This research projects to not only to forecast the stock closing price but also to compare the results of LSTM, CNN and RNN. To compare the built models, all models for each stock should have same hyperparameters such as epochs, batch size, learning rate as well as same training and validating data size, same optimizer, and loss function. In these experiments, the finalized configurations for all training models are:

- epochs : 150
- batch size : 10
- learning rate : 0.001
- splitting data : 80% for training and 20% for testing
- optimizer : Adam
- loss function : Mean Square Error (MSE)

D. Evaluating models

1) Models for NVIDIA: For NVIDIA, three different deep learning models LSTM, CNN and RNN are built and evaluated. Each model is trained and tested under same conditions using identical training data, batch size and epochs to be fair comparison.

LSTM Model

Although LSTM is ideal for sequential data, LSTM model cannot capture well the patterns of NVIDIA data. The MAE and RMSE are higher than the other two models.

- MAE : 9.045
- RMSE : 15.657

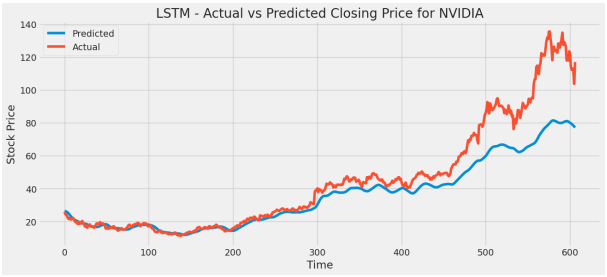

Fig. 6. LSTM - Predicting Closing Price of NVIDIA

CNN Model

CNN performs well but the error rate is slightly higher than RNN model. It might be occurred that CNN is more specialized for spatial data than sequential ones.

- MAE : 1.904
- RMSE : 2.955

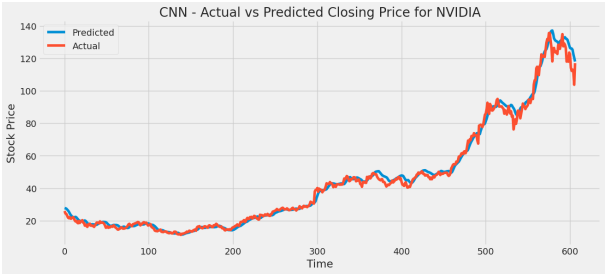

Fig. 7. CNN - Predicting Closing Price of NVIDIA

RNN Model

RNN model outperforms the CNN model for both MAE and RMSE values. Although RNN has the limitations in learning long-term dependencies,it can predict with most accuracy for NVIDIA stock.

- MAE : 1.624
- RMSE : 2.761

Among three models, RNN model becomes the most appropriate model for NVIDIA stock which data might be more effective with simple recurrent architecture to capture the important patterns in data.

2) Models for Micron Technology: Similar to NVIDIA, three different deep learning models LSTM, CNN and RNN are built and evaluated for Micron Technology. Each model is trained and tested under same conditions using identical training data, batch size and epochs to be fair comparison.

LSTM Model

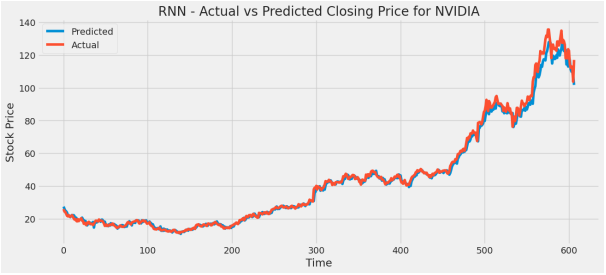

Fig. 8. RNN - Predicting Closing Price of NVIDIA

LSTM for Micron Technology shows stronger and more accurate when compared to LSTM prediction for NVIDIA. Among three models of Micron Technology, LSTM performs better than RNN, but slightly higher MAE and RMSE than CNN.

- MAE : 3.748
- RMSE : 5.809

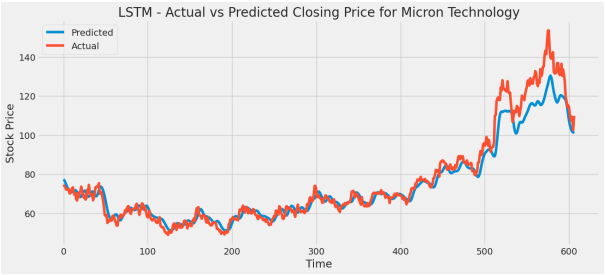

Fig. 9. LSTM - Predicting Closing Price of Micron Technology

CNN Model

Interestingly, CNN outperforms in term of MAE and RMSE lowest values when comparing with LSTM and RNN. Although CNN is well-known for image related dataset, CNN achieves the most accurate prediction for Micron Technology stock data.

- MAE : 1.909
- RMSE : 2.601

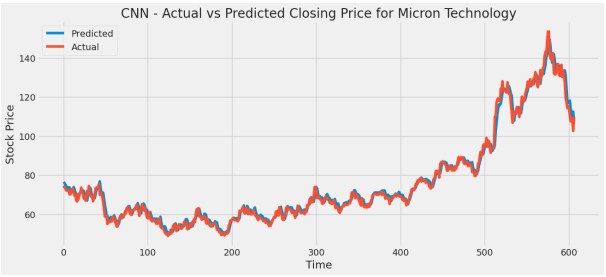

Fig. 10. CNN - Predicting Closing Price of Micron Technology

RNN Model

RNN model performs a higher error rates when it is compared to CNN and LSTM. For Micron Technology, RNN might struggle to capture the temporal dependencies.

- MAE : 19.706
- RMSE : 24.463

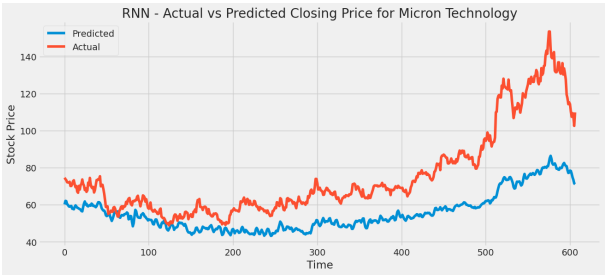

Fig. 11. RNN - Predicting Closing Price of Micron Technology

Among three models, CNN model achieves itself as the most suitable model for Micron Technology stock. In this prediction scenario, CNN could be able to extract features to be aligned with data patterns and it makes to perform more accurate prediction for stock prices.

3) Combined Analysis: When comparing the MAE and RMSE of all models from NVIDIA and Micron Technology in TABLE II, RNN is the most suitable for NVIDIA meanwhile CNN outperforms for Micron Technology to predict the closing price data.

TABLE II
COMPARISON OF MAE AND RMSE ACROSS MODELS

Stock	Model	MAE	RMSE
NVIDIA	LSTM	9.045	15.657
	CNN	1.904	2.955
	RNN	1.624	2.761
Micron Technology	LSTM	3.748	5.809
	CNN	1.909	2.601
	RNN	19.706	24.463

V. CONCLUSIONS AND FUTURE WORK

For NVIDIA stock, CNN and RNN models outperform than LSTM model with significant lower values in MAE and RMSE. RNN demonstrates the best performances with lowest MAE as 1.624 and RMSE as 2.761. Meanwhile CNN becomes the most suitable model for Micron Technology with lowest error rates (MAE - 1.909, RMSE - 2.601) although LSTM also performs better RNN model. For these experiments, CNN model for both stocks provides consistent performance. Therefore, CNN can be said that it is effectively working for spatial data as well as for the sequential data. For RNN model, it obtains better result in NVIDIA data but highest error rates in Micron Technology data. So, the performance of RNN can depend on the nature and characteristic of data. For LSTM, despite being the ideal for time-series analysis, its performance is not consistent as CNN model. Although it perform moderately for Micron Technology, its error rate for NVIDIA is significantly higher. To be summarized, selecting model will depend on the characteristic of stock price data, therefore, it is better to compare the models rather than training only one model for predicting stock prices. In future, the most accurate

models of NVIDIA and Micron Technology will be fine-tuned and find the correlation with other commodities. Subsequently, the stock data and related commodities trends will also be trained and evaluated. A light-weighted application would be developed to be streamlined for checking the stock prices from application so that the traders and stock holders can make decision to buy or sell when a related stock or commodity price increases.

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REFERENCES

[1] A. Bansal, "AI In Financial Services: Transforming Stock Trading," Forbes: Innovation, Mar. 04, 2024. [Online] Available: https://www.forbes.com/sites/forbestechcouncil/2024/03/01/ai-in-financial-services-transforming-stock-trading/ [Accessed on: Jun. 24, 2024].

[2] M. Hiransha, E.A. Gopalakrishnan, V. K. Menon and K.P. Soman, "NSE Stock Market Prediction Using Deep-Learning Models," Procedia Computer Science, vol. 132, pp. 1351–1362, 2018. [Online]. Available: https://doi.org/10.1016/j.procs.2018.05.050 [Accessed on: Jun. 24, 2024].

[3] R. Krause, "AI Stocks: Tech Giants, Cloud Titans, Chipmakers Battle For An Edge," *Investor's Business Daily*, June 24, 2024. [Online]. Available: https://www.investors.com/news/technology/artificial-intelligence-stocks/ [Accessed on: Jun. 24, 2024].

[4] M. Montierth, "Latest NVIDIA GPUs powered by innovation, collaboration and Micron GDDR6X," Micron Technology Inc. [Online]. Available: https://www.micron.com/about/blog/company/partners/latest-nvidia-gpus-powered-by-innovation-collaboration-micron-gddr6x [Accessed on : Jun. 24,2024].

[5] NasdaqGS, "NVIDIA Corporation (NVDA)." [Online]. Available: https://finance.yahoo.com/quote/NVDA/history/?period1=1561414921&period2=1719267684&frequency=1mo [Accessed on: Jun. 25, 2024].

[6] NasdaqGS, "Micron Technology, Inc. (MU)." [Online]. Available: https://finance.yahoo.com/quote/MU/history/?period1=1561414921&period2=1719267684&frequency=1mo [Accessed on: Jun. 25, 2024].

[7] NasdaqGS, "Alphabet Inc. (GOOGL)." [Online]. Available: https://finance.yahoo.com/quote/GOOGL/history/?period1=1561414921&period2=1719267684&frequency=1mo [Accessed on: Jun. 25, 2024].

[8] NasdaqGS, "Meta Platforms, Inc. (META)." [Online]. Available: https://finance.yahoo.com/quote/MSFT/history/?period1=1561414921&period2=1719267684&frequency=1mo [Accessed on: Jun. 25, 2024].

[9] NasdaqGS, "Microsoft Corporation (MSFT)." [Online]. Available: https://finance.yahoo.com/quote/META/history/?period1=1561414921&period2=1719267684&frequency=1mo [Accessed on: Jun. 25, 2024].

[10] NasdaqGS, "Apple Inc. (AAPL)." [Online]. Available: https://finance.yahoo.com/quote/AAPL/history/?period1=1561414921&period2=1719267684&frequency=1mo [Accessed on: Jun. 25, 2024].

[11] W. Williams, "Timeline of U.S. Stock Market Crashes," *Investopedia*, May 04, 2024. [Online]. Available: https://www.investopedia.com/timeline-of-stock-market-crashes-5217820 [Accessed on: Jun. 25, 2024].

[12] R. Ahuja, Y. Kumar, S. Goyal, S. Kaur, R. K. Sachdeva and V. Solanki, "Stock Price Prediction By Applying Machine Learning Techniques," in *2023 International Conference on Emerging Smart Computing and Informatics (ESCI), Pune, India, March 01-03, 2023*, pp. 1-5. [Online]. Available: https://ieeexplore.ieee.org/document/10099614https://ieeexplore.ieee.org/document/10099614 [Accessed on: Jun. 26, 2024].

[13] H. Ezzeddine and R. R. Achkar, "Ensemble Learning in Stock Market Prediction," in *ICMLC '21: Proceedings of the 2021 13th International Conference on Machine Learning and Computing, Shenzhen China, 26 February - 1 March, 2021*, pp. 298–303. [Online]. Available: https://dl.acm.org/doi/10.1145/3457682.3457727 [Accessed on: Jun. 26, 2024].

[14] N. Adlakha, Ridhima and A. Katal, "Real Time Stock Market Analysis," in *2021 International Conference on System, Computation, Automation and Networking (ICSCAN), Puducherry, India, July 30-31, 2021*, pp. 1-5. [Online]. Available: https://ieeexplore.ieee.org/document/9526506 [Accessed on: Jun. 26, 2024].

[15] C. H. Cho, G. Y. Lee, Y. L. Tsai, K. C. Chan, "Toward Stock Price Prediction using Deep Learning" in *UCC '19 Companion: Proceedings of the 12th IEEE/ACM International Conference on Utility and Cloud Computing Companion, Auckland, New Zealand, December 2 - 5, 2019*, pp.133–135. [Online]. Available: https://dl.acm.org/doi/proceedings/10.1145/3368235https://dl.acm.org/doi/proceedings/10.1145/3368235 [Accessed on: Jun. 27, 2024].

[16] A. Moghar and M. Hamiche, "Stock Market Prediction Using LSTM Recurrent Neural Network," Procedia Computer Science, vol. 170, pp. 1168-1173, 2020. [Online]. Available: https://doi.org/10.1016/j.procs.2020.03.049 [Accessed on: Jun. 27, 2024].

[17] K. R. Reddy, B. T. Kumar, V. R. Ganesh, P. Swetha and P. K. Sarangi, "Stock Market Prediction Using Recurrent Neural Network," in 2022 IEEE International Conference on Current Development in Engineering and Technology (CCET), Bhopal, India, December 23-24, 2022, pp. 1-4. [Online]. Available: https://ieeexplore.ieee.org/document/10080154https://ieeexplore.ieee.org/document/10080154 [Accessed on: Jun. 27, 2024].

[18] W.M. Shaban, E. Ashraf and A.E. Slama, "SMP-DL: a novel stock market prediction approach based on deep learning for effective trend forecasting," Neural Computing & Applications, vol. 36, pp. 1849–1873. 2024. [Online]. Available: https://doi.org/10.1007/s00521-023-09179-4 [Accessed on: Jun. 28, 2024].

[19] S. Das, A. Tariq, T. Santos, S. S. Kantareddy, I. Banerjee. "Chapter 4 Recurrent Neural Networks (RNNs): Architectures, Training Tricks, and Introduction to Influential Research," in Machine Learning for Brain Disorders [Internet], New York, Humana, 2023. [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK597502/ [Accessed on: Jun. 28, 2024].

[20] S. Chen, H. He, "Stock Prediction Using Convolutional Neural Network" in 2018 2nd International Conference on Artificial Intelligence Applications and Technologies (AIAAT 2018), Shanghai, China, August 8–10, 2018. [Online]. Available: https://iopscience.iop.org/article/10.1088/1757-899X/435/1/012026 [Accessed on: Jun. 28, 2024].

[21] S. Mehtab ,J. Sen, "Stock Price Prediction Using Convolutional Neural Networks on a Multivariate Time Series." [Online]. Available: https://www.techrxiv.org/users/680961/articles/677367-stock-price-prediction-using-convolutional-neural-networks-on-a-multivariate-time-series [Accessed on : Jun. 29,2024]

[22] Y. Zhu, "Stock price prediction using the RNN model" in 2020 International Conference on Applied Physics and Computing (ICAPC 2020), 2020. [Online]. Available: https://iopscience.iop.org/article/10.1088/1742-6596/1650/3/032103 [Accessed on: Jun. 29, 2024].

[23] A. Chugh, "MAE, MSE, RMSE, Coefficient of Determination, Adjusted R Squared — Which Metric is Better?" [Online]. Available: https://medium.com/analytics-vidhya/mae-mse-rmse-coefficient-of-determination-adjusted-r-squared-which-metric-is-better-cd0326a5697e [Accessed on: Jun. 30, 2024].