

# Stock price prediction with long short-term memory

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**Abstract.** Stock forecasting aims to predict future stock prices based on past price changes in the market, playing an essential role in the field of financial transactions. However, since the stock market is highly uncertain, stock prediction is complex and challenging. This paper uses the long short-term memory (LSTM) model to predict the stock market and compares it with the current stock prediction algorithm. Firstly, we preprocessed the raw dataset and normalized data into the range from 0 to 1. Secondly, we introduced the LSTM model and improved its performance by tuning four parameters: learning rate, number of hidden layers, number of epochs, and batch size. Finally, we use four evaluation metrics to evaluate models: mean average error (MAE), root mean square error (RMSE), coefficient of determination (R2), and mean absolute error percentage (MAPE). Our LSTM model performs better than the previous model in experiments in terms of MAE, RMSE, R2, and MAPE.

**Keywords:** component, long-short term memory (LSTM), K-Nearest Neighbors Algorithm (KNN), stock price prediction, machine learning, Recurrent Neural Network (RNN).

## 1. Introduction

The stock market is an integral part of the economy because it organizes resources and channels them to proper investments [1]. Stock price reflects the value in the market and broadly represents the economy's tendency. Since the stock price is a typical indicator of economic status and a bellwether of financial investment, stock price prediction has been a hot field for economists. By predicting stock prices, investors can make huge profits and hedge risks, and such economic activity also increases the transparency and efficiency of the capital market.

However, the stock market is highly dynamic and intercorrelated, and stock price prediction with high accuracy is challenging. For a substantial modern market, excessive data scale and complex environment make the act of prediction more difficult [2]. In addition, multiple linear and nonlinear factors exist, such as time lag problems, inefficient data used in the empirical study, and reflexivity in the market, making stock prices volatile and dynamic and affecting the prediction model [3][4].

Computer scientists have invented multiple prediction models based on different algorithms to participate in market prediction. Long Short-Term Memory (LSTM) was first presented by S. Hochreiter and J. Schmidhuber in 1997 [5]. LSTM is one special Recurrent Neural Network model. Unlike regular RNN models with only one hidden state, LSTM has one more transmission state: the cell state [6]. By controlling the state of gates, the LSTM model forgets less critical information, remembers valuable information, and thus performs better in long-term prediction [7].

This paper uses LSTM to predict the stock price and improve the accuracy of the result. The dataset used in this paper includes monthly stock prices of Tesla from 9/30/2019 to 4/11/2022. The data is arranged in 7 columns: the Date, the Highest price, the Lowest price, the Opening price, the Closing price adjusted for splits and dividends, the Stock volume, and total turnovers. We preprocessed the data by normalizing them to the range from 0 to 1 and splitting them into 70% train and 30% test sets.

We trained the LSTM model and evaluated it with four standards: mean average error, root mean square error, coefficient of determination, and mean absolute error percentage. Compared with the baseline K-nearest neighbors (K-NN) algorithm method, our LSTM performs better in these four terms of evaluation metrics.

## 2. Proposed Method

This section discusses the proposed method. First, the dataset is split into 70% train set and 30% test set. Then, we normalized the data (Sec. 2.1). Next, we presented the structure of our LSTM model (Sec. 2.2). In Section 2.3, we presented the process of getting optimal parameters used in our model.

### 2.1. Data Pre-Processing

We used seven parameters to extract the dataset's features, shown in Table 1.

**Table 1.** Parameters used.

Date	The Date
High	The Highest price
Low	the Lowest price
Open	the Opening price
Close	the Closing price adjusted for splits and dividends
Volume	the Stock volume
Turnover	Total turnovers

Before normalizing the data, we split the dataset into two sets with the ratio of 70% training set and 30% test set. The train set is before the test set because the model is a time-series prediction [8]. Since stock prices are distributed in different ranges, the nonlinear dataset cannot be applied in the LSTM model. In this case, we applied the MinMaxScaler function to normalize the dataset [8]. The MinMaxScaler transformation is defined as (1) and (2). We set min as 0 and max as 1, and thus data in the normalized train set are in the range from 0 to 1.

$$x^{std} = \frac{x - \min(x)}{\max(x) - \min(x)} \quad (1)$$

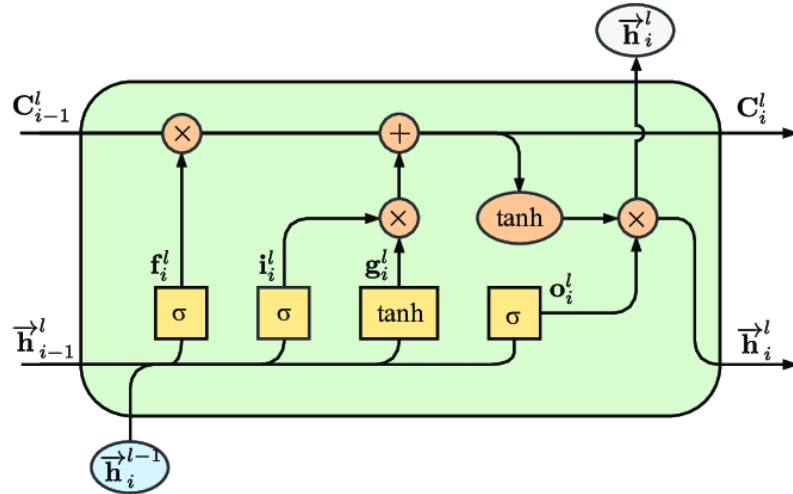
$$x^{scaled} = x^{std} \times (max - min) + min \quad (2)$$

### 2.2. LSTM structure

LSTM performs better than the regular RNN model because it can solve long-term dependency problems. In order to control the loss of features from the dataset, LSTM implements gate mechanism, and the LSTM model is composed of a series of LSTM units [9]. The structure of one LSTM nit is shown in figure 1 [10].

The core part of LSTM is the cell state. As figure 1 shows, the cell state's input is  $C_{i-1}$ , and its output is  $C_i$ . The equation is defined as equation (3):

$$C_t = f_t \cdot C_{t-1} + i_t \cdot \tilde{C}_t \quad (3)$$



**Figure 1.** The architecture of LSTM.

In equation (3),  $f_t$  is called forget gate, which forgets less important data from the previous data [10].  $i_t$  is called input gate, which determines and writes information onto the Internal Cell State. The formulas are defined below:

$$f_t = \sigma(W_f \cdot [h_{t-1}, x_t] + b_f) \quad (4)$$

$$i_t = \sigma(W_i \cdot [h_{t-1}, x_t] + b_i) \quad (5)$$

$$\tilde{C}_t = \tanh(W_C \cdot [h_{t-1}, x_t] + b_C) \quad (6)$$

The output gate  $\sigma_t$  determines the output from the current state, and the formula is defined below:

$$\sigma_t = \sigma(W_\sigma \cdot [h_{t-1}, x_t] + b_\sigma) \quad (7)$$

$$h_t = \sigma_t \cdot \tanh(C_t) \quad (8)$$

### 2.3. Tuning Parameters Process

We have an initial guess of optimal parameters and set the learning rate as 0.01, the number of hidden layers as 32, the number of epochs as 10, and the batch size as 16. First, we only change the learning rate and keep other parameters unchanged. Then we use four evaluation metrics to evaluate the results with different learning rates. As Table 2 shows, MAE, R2, RMSE, and MAPE reach the lowest value, and R square also reaches the highest value when we set the learning rate as 0.005. Therefore, the optimal learning rate is 0.005.

**Table 2.** Changing learning rate.

Learning rate	Epoch	Batch size	Hidden layers	MAE	R2	RMSE	MAPE
0.0001	10	16	32	0.0552	0.6423	0.0642	46.65
0.001	10	16	32	0.0541	0.6294	0.0658	46.25
0.005	10	16	32	0.0505	0.6621	0.0641	43.19
0.01	10	16	32	0.0516	0.6431	0.0642	44.16
0.05	10	16	32	0.0573	0.6407	0.0718	50.03

In Table 3, Since the optimal learning rate is 0.005, we only kept the learning rate unchanged and changed the number of epochs. The optimal epoch number is 30.

**Table 3.** Changing the number of Epoch.

Learning rate	Epoch	Batch size	Hidden layers	MAE	R2	RMSE	MAPE
0.005	10	16	32	0.0552	0.5711	0.0642	46.65
0.005	20	16	32	0.0447	0.4099	0.0569	39.33
0.005	30	16	32	0.0419	0.4704	0.0547	33.36
0.005	40	16	32	0.0586	0.3108	0.0741	38.94
0.005	5	16	32	0.0606	0.3318	0.0708	59.58

In Table 4, we set the number of epochs as 30. The optimal batch size is 16.

**Table 4.** Changing batch size.

Learning rate	Epoch	Batch size	Hidden layers	MAE	R2	RMSE	MAPE
0.005	30	8	32	0.0585	0.2073	0.0700	63.79
0.005	30	16	32	0.0426	0.4852	0.0560	34.33
0.005	30	32	32	0.0508	0.4378	0.0686	40.58
0.005	30	64	32	0.0653	0.1934	0.0830	66.94
0.005	30	128	32	0.0645	0.2674	0.0808	65.03

In Table 5, we only change hidden layers. The optimal number of hidden layers is 32.

**Table 5.** Changing the number of hidden layers.

Learning rate	Epoch	Batch size	Hidden layers	MAE	R2	RMSE	MAPE
0.005	30	16	2	0.0664	0.2477	0.0782	64.14
0.005	30	16	4	0.0513	0.310	0.0638	47.97
0.005	30	16	8	0.0608	0.073	0.4156	54.66
0.005	30	16	16	0.0540	0.2337	0.0651	49.98
0.005	30	16	32	0.0447	0.5344	0.0597	33.357

Finally, we chose the optimal parameters: the learning rate is 0.005; the number of epochs is 30; the batch size is 16; the number of hidden layers is 32.

### 3. Experimental Result

This section discusses the experiment and the result. We introduced the dataset, the baseline method, and evaluation metrics used in the experiment (Sec. 3.1). Next, we presented the results of our LSTM model and KNN model in the experiment (Sec. 3.2). Then we compared the performance of two models and analyzed the result. (Sec. 3.3)

#### 3.1. Experiment Setting

*3.1.1. Dataset.* The dataset used in this paper is Tesla INC from 9/30/2019 to 4/11/2022. The sample of the dataset is shown in Table 6.

**Table 6.** Sample data from the dataset.

Date	High	Low	Open	Close	Volume	Adj Close
2019/9/30	48.796	47.222	48.6	48.174	29399000	48.174
2019/10/1	49.19	47.826	48.3	48.938	30813000	48.938
2019/10/2	48.93	47.886	48.658	48.626	28157000	48.626
2019/10/3	46.896	44.856	46.372	46.606	75422500	46.606
2019/10/4	46.956	45.614	46.322	46.286	39975000	46.286
2019/10/7	47.712	45.71	45.96	47.544	40321000	47.544

*3.1.2. Baseline Method.* This paper used a model based on the K-nearest neighbors algorithm as the baseline method [11]. KNNs are characterized by a fast-training process and save all training data. We used the same dataset to train KNN models in the range of 1 to 300 and chose the one with the lowest MAE, RMSE, and MAPE to compare with our LSTM model.

*3.1.3. Evaluation Metrics.* We use four evaluation metrics: root mean square error, mean average error, mean absolute error percentage, and the coefficient of determination, and they are defined as (9) (10) (11) (12):

$$MAE = \frac{1}{n} \sum_{i=1}^N |(Prediction_i - Real_i)| \quad (9)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^N \omega_i (Prediction_i - Real_i)^2} \quad (10)$$

$$R2 = 1 - \frac{\sum_{i=1}^N (Prediction_i - Real_i)^2}{\sum_{i=1}^N (Mean(Real)_i - Real_i)^2} \quad (11)$$

$$MAPE = \frac{1}{n} \sum_{i=1}^N \frac{|(Prediction_i - Real_i)|}{Real_i} \quad (12)$$

When MAE, RMSE, and MAPE are low, it represents that the forecasting task has less error and performs better. R2 is the coefficient of determination which is larger for better performance.

### 3.2. Result

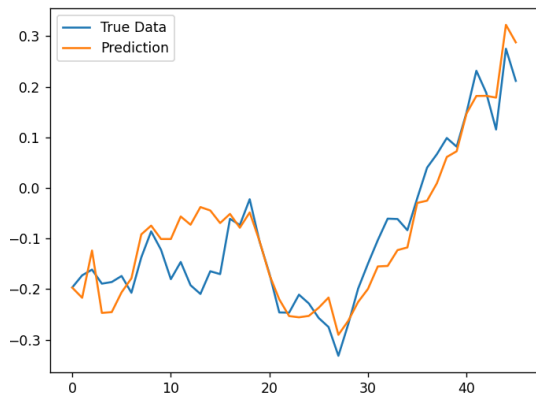
In our experiment, the LSTM model and KNN model are evaluated in terms of four evaluation metrics. Table 7 shows the result of our LSTM model and KNN model, respectively.

**Table 7.** Result of Experiments.

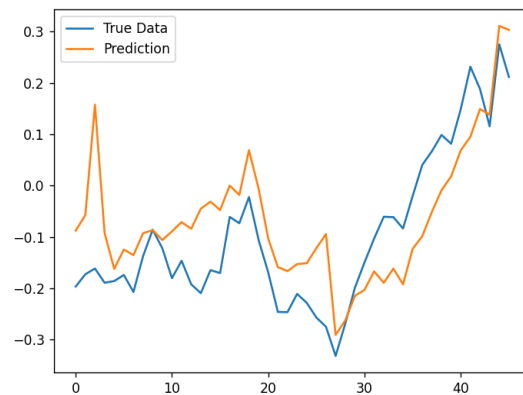
	MAE	RMSE	R2	MAPE
LSTM	0.0423	0.0559	0.4805	0.3176
KNN	0.0867	0.1523	0.1021	0.8480

As Table 7 shows, the LSTM model has the result with lower MAE, RMSE, MAPE, and higher R2, performing better than the KNN model.

We visualize prediction data and real data. Figure 1 plots the relationship between the actual data and the prediction from LSTM; Figure 2 plots actual data and the prediction from the KNN model.



**Figure 2.** Result of LSTM.



**Figure 3.** Result of KNN.

### 3.3. Analysis

In figure 2, the prediction stock price is close to the real price, and the prediction line also reflects trends of real data; In figure 2, although the prediction data reflects the basic trends of real data, the predicted result is rough and inaccurate compared with figure 1. The lag problem also occurs in figure 2 and makes KNN inefficient in reflecting changes of stock price.

In conclusion, LSTM performs better than the KNN model in terms of both four evaluation metrics and visualized graphs.

## 4. Conclusion

This paper uses the LSTM model to perform best when we set hidden layers as 32, learning rate as 0.02, batch size as 32, and epochs as 250. The LSTM model has better performance than the average KNN model based on the evaluation metrics of MAE, RMSE, R2, and MAPE. In the future, we will continuously work on this issue to improve the accuracy by adding the Convolutional neural network into the Long Short-term Memory model; we will also study how to maintain performance stability.

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