A Hybrid Model Combined Deep Learning Approaches in Stock Price Prediction

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***Abstract*—Stock price forecasting is always an important task, but because many factors determine the stock price, the variability of its market makes the stock prediction complex and challenging. The stock price prediction is indispensable because the correct stock price prediction can help investors make better decisions and reduce investment risks. The historical price of the stock is only one of the many factors that affect the trend of stock price. Therefore, researchers combine various factors and use machine learning to put forward new models to promote stock price prediction constantly. Nowadays, machine learning has become more widely used in stock price prediction. Compared with traditional technologies, machine learning can predict time series data with high precision and minimize errors and risks. This study aims to review and summarize some existing literature and determine the prediction direction and challenges of the future stock market. We classified the works of literature with similar research methods and backgrounds, and we also introduced the main models. Three categories formed: Support Vector Machine (SVM) studies, Empirical Mode Decomposition (EMD), and Long-Short Term Memory (LSTM) studies, and studies using morphological similarity clustering and hierarchical temporal memory. The last two sections provide the overall conclusions and future research challenges**

Keywords—Neural Network, Stock Price Prediction, Deep Learning, Time Series

I. INTRODUCTION

Stock market prediction debate is always at the centre of financial economies. Economies and businessmen are curious and trying to find an accurate prediction method of the share price movement that can determine the future tendency of the stock value in every financial exchange. Since the stock price is always a reflection of a company's value or a market value, the stock price prediction can not only help the investors reduce more financial risks and make more profits, but also increase market efficiency. Setting aside traditional and limited predictive factors of stock price, scholars and economists turned their focus to social media and news to find if there is additional and useful information that has been overlooked should be valued [8]. However, because there are too many uncertain and abstract factors in stock forecasts, such as the investors' sentiment, which will make the stock price prediction more complicated, several hybrid models which combine with a deep learning approach will be applied in this review paper.

This review paper highlights three Neural Network Models for stock market analysis and stock price forecasts. The first one is the Long-Short Term Memory (LSTM) model. The second one is the Support Vector Machine (SVM) model, which applies classification algorithms for two-group classification problems and will reduce structural risks. The last one is the Empirical Mode Decomposition (EMD) model. Besides these three models, this paper also studies morphological similarity clustering and hierarchical temporal memory.

To overcome the limitation and difficulties of the high empirical risks and the problem of different analysts hold different sentiment about the same piece of news because of conservatism or overconfidence, we have to take a review on the previous studies, try to find the advantages of each model, and build a new hybrid model to improve the stock price predictive power [8].

The remainder of this review paper will be organized into the following format. Firstly, it will introduce the background with specific examples and benchmarks of text classification and three different prediction indexes. Then, it will move to an in-depth discussion and introduction of the three latest and common neural-based approaches for text classification with word and mathematical explanation. Furthermore, a summary of some related research on text classification will be followed by analyzing the challenges and problems in current research work. This review paper will end with an overall conclusion and some future ideas on predicting stock prices.

II. BACKGROUND OF STOCK PRICE PREDICTION

In the last few decades, text classification has been applied and studied in various fields and industries. Also, with the advance of technology, an increasing number of researchers are dedicating their energy and passion to this field of study. Some specific text classification applications include email or text message classification, which determines whether incoming mail or text message is sent to the inbox or filtered into the spam folder. Another wide implemented application of text classification is to find the sentiment of comments or messages online. This one can be instrumental in the censorship of social media, and it could avoid the happening of dangerous and improper language such as racism or terrorism. The text classification obviously could be applied to many other, very disparate fields.

In this study, we will use the text classification and many methods derived from it to predict the prices in the stock market. The first step of text classification is gathering data. Our data set for this research comes from the Shanghai Stock Exchange Composite Index (SSE) and Citi Group

stock utilizing 01/01/2013 – 12/31/2016. These two data are available online, and we could then freely get them and do the analysis. The particular part about these two data sets is that they are in detail, and we could even extract the daily or even hourly prices in the market. This character of these two data sets makes researchers and us able to make analysis and prediction easily.

For this review paper, we summarized two different prediction indexes that can predict stock prices correctly. The first one is about financial news articles. The researchers found that financial news articles have affected the system of stock price trend forecasts. And the overall process of how they work was as follows: Financial news broadcast an event. Investors interpret this message and then spread it to the buy/sell intention. Investors make the final decision. Nowadays, enterprises rely more and more on news articles, so financial news reports have become a crucial factor that cannot be ignored in stock price prediction. Therefore, the researchers proposed a novel twin support vector machine with a fuzzy hyperplane for predicting stock price trends [5]. However, language is euphemistic and vague; hence researchers used fuzzy theory to treat the rules of human language as numerical calculation to solve the ambiguous and uncertain information in news reports [5]. In addition, there are potential fuzzy boundaries between upward and downward trends [5]. Therefore, when constructing classifiers, we should exert varying degrees of importance and influence on them.

The prediction indexes used in the Empirical Mode Decomposition (the latter section provides detail on what this method is) is Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE). These indexes are easy to understand: they measure the difference between reality and prediction in the absolute, root mean sure, and represent absolute percentage form. With these tools, we can have a good understanding of the accuracy of our model, and we could also be based on the results to improve or train our model, making them have a better performance.

III. Neural Network Model

A. LSTM Long-Short Term Memory

The first Neural Network approach should be highlighted is the Long Short-Term Memory (LSTM) which is one of the derivatives of the Recurrent Neural Network (RNN) used in the field of deep learning [7]. It is used to analyze the technical indicators in the stock market. The main contribution and significance of it is it has feedback connections and self-loop which is more flexible in controlling the outputs, and it is also able to handle long-term dependency in a time series [1]. Additionally, it prevents sequential data from exploding and vanishing gradients [1].

According to Jing et al., the LSTM neural network approach is applied to analyze the technical indicators which selected from the above investors' sentiments and stock quote and predict the stock prices [8].

Below is a mathematical prediction model which defines the jth neuron at time t in the LSTM approach:

$$i_t^j = \sigma(U_i x_t + w_i h_{t-1} + b_i)^j \quad (1)$$

$$f_t^j = \sigma(U_f x_t + w_f h_{t-1} + b_f)^j \quad (2)$$

$$o_t^j = \sigma(U_o x_t + w_o h_{t-1} + b_o)^j \quad (3)$$

$$c_t^j = f_t^j c_{t-1}^j + f_t^j \tilde{c}_t^j \quad (4)$$

$$\tilde{c}_t^j = tanh(U_c x_t + w_c h_{t-1} + b_c)^j \quad (5)$$

$$h_t^j = o_t tanh(c_t^j) \quad (6)$$

where x_t is the input data and h_t is the hidden state at time t. c_t^j is a memory cell and i_t^j is the input gate which controls the added amount of new information, f_t^j is the forget gate and o_t^j is the output gate on the jth neuron. $\tilde{c}_t^j$ is the input modulate gate to filter new information. U_i, U_f, U_o, U_c, w_i, w_f, w_o and w_c are weight matrices, b_i, b_f, b_o and b_c are the bias terms. σ is a sigmoid function [8]. Below is a figure of our architecture of the LSTM Model (Figure 1. the architecture of LSTM).

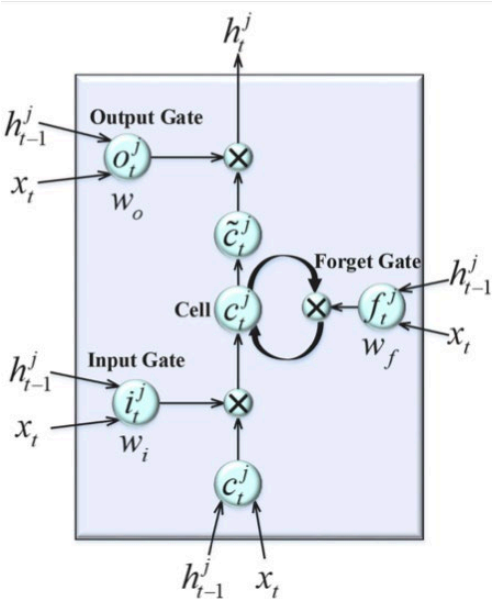

Figure 1.The architecture of LSTM

B. Support Vector Machine (SVM) Model

Vapnik and Chervonenkis proposed VC learning theory to explain the learning progress from a statistical point of view, and based on that, they developed the support vector machine (SVMs) [12]. The key insight of support vector machines (SVMs) is that they make them more critical of those points closest to the separating hyperplane, called support vectors, than other points [12]. These support vectors are the data points most difficult to classify while they directly affect the optimal position of the decision surface (Berwick). When SVMs construct a learning machine, it only assigns non-zero weight to these support vectors, maximizing the margin around the separating hyperplane. Therefore, it performs good generalization ability [12]. The form of the equation defining the decision surface separating the classes is a hyperplane of the form: $w^T x + b = 0$; where w is the weight vector, x is the input vector, and b is bias. In predicting stock prices, SVMs is a machine learning algorithm that can classify the future stock price direction (up or down), which performs better than

most traditional learning machines. This algorithm has proven to be one of the most influential supported supervised learning algorithms [12].

C. Empirical Mode Decomposition (EMD) Model

The stock market price, a non-stationary time series data, is perfectly fitted with the EMD methods [13]. During the past two decades, various scholars and experts used EMD or EMD with other methods to design a model better than the traditional one in terms of Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) [13]. The fundamental idea of the EMD is that it decomposes the original signal into a series of intrinsic mode function (IMF) with different time-scale [6]. After this transformation, we could then calculate the mean different methods, such as Hilbert-Huang transformation, to calculate the instantaneous phase of the IMF accordingly and apply the analysis or further training. In general, the EMD method is so special that it extracts the extreme, continuously predicting the short-term outcomes and finally getting the long-term trend. This is a method similar to GMM which is also a good way of predicting the stock market prices. In conclusion, different research papers with different approaches find that the EMD is an excellent method apart from the traditional stationary analysis. No matter applying it solely or combining it with other methods to make a hybrid analytical tool, the EMD provides a creative, extraordinary, and accurate way to predict the stock market prices.

IV. Related Research on Text Classification

A. Studies Using Novel Twin Support Vector Machine with Fuzzy Hyperplane to Predict Stock Prices

The first article that primarily focuses on stock prices prediction using support vector machines. Compared with most methods that only focus on predicting stock price through historical data, Hao et al. made up for the problem of ignoring the critical news that may affect the stock price [5]. They extracted the hidden topic model and emotional information from many news articles to help investors make better choices. In addition, they used fuzzy sets to filter the financial market's uncertain and inaccurate observation information to reduce the impact of outliers on SVM classification technology. Experiments showed that the prediction model proposed by Hao et al. was more suitable for data with outliers [5]. Also, compared with traditional technologies of extracting keywords, the combination with the hidden topic and emotional information could improve the characteristics of article content and significantly reduce the dimensionality of the article vector. However, risk control needs to improve in the future.

B. Studies Using Empirical Mode Decomposition, Long - Short Term Memory and Neural Networks to Forecast Stock Price

The second group of articles includes studies mainly using empirical mode decomposition, long-short term memory and neural network to make stock prices prediction. Shu and Gao proposed and built a novel hybrid model by combining empirical mode decomposition (EMD), convolutional neural network (CNN), and Long-Short Term Memory (LSTM) to predict stock price [1]. They studied the data that came from Shanghai Stock Exchange Composite Index (SSE). They divided the original stock price into four subsequences, then used EMD to decompose each sequence, CNN to obtain the frequency representation, and LSTM to model the time correlation of the extracted features, finally achieving the price prediction through a linear transformation. They took advantage of the characteristics of CNN that obtained the frequency representation, which solved the issues ignored by previous researchers, and made one-day and one-week predictions respectively. The experimental results showed that this novel hybrid network could achieve better performance than other state-of-the-art models. In addition, they studied the impact of frequency information on prediction performance. They concluded that different frequency components represented different time scales and deleting noise and o features components could improve the prediction accuracy for long-term; residual described the most compelling feature of great significance to prediction performance.

Jing et al. proposed a novel hybrid model which combines a deep learning method with a sentiment analysis model to predict the price of stock price [8]. The authors make some brief literature review about the stock market prediction by applying sentiment analysis in social media and machine learning methods on time series analysis which are two important and central methods in academic finance research. Then, they used the Artificial Neural Network (ANN) which can handle nonlinear, discontinuous, and high-frequency data to predict the stock market. The hybrid prediction model consists of three parts, pre-processing data which aims to process the textual and technical data, analysing investor sentiments which employs a sentiment analysis model to classify the textual data from the online social network, and building a prediction model which will apply Long Short-Term Memory (LSTM) neural network method to predict stock price in the end. In the experiment, the authors chose the Chinese A-share market and randomly selected five stocks of each industry twenty times to conduct the prediction experiments. They concluded that this novel hybrid model can give a comprehensive description for the prediction in the financial market after processing raw data. However, since the financial policy will defer in different countries, we cannot promise this stock price prediction method is suitable for other countries.

C. Studies Using Morphological Similarity Clustering and Hierarchical Temporal Memory to Predict Stock Price

The third article mainly focuses on using morphological similarity clustering and hierarchical temporal memory to predict stock price. Since the price data is a specific time-series data, Recurrent neural network (RNN), long short-term memory (LSTM), and gated recurrent units (GRU) have been frequently applied to solve and analyze stock prices. Nonetheless, most studies prefer to explore stocks individually, ignoring the correlation between similar stocks in the entire market. And they plan to further enhance the accuracy of prediction and generalization of the model by developing algorithms that can consider more variables to find similar stocks [10].

V. Challenges

Stock price forecasting is still a challenging task. Although researchers have tried many different methods and combined more models to improve the prediction system, there are still deficiencies and space for improvement. Now researchers analyse the change in stock

price from the past historical data and develop important information from news articles to help investors make more accurate predictions. In the future, researchers will focus on using social media to help predict stock trends [5]. Although researchers have solved the problem of time series, they could combine financial features on the original basis. They could use integrated empirical mode decomposition (EEMD) and complementary integrated practical mode decomposition to improve the prediction accuracy and carry out price prediction based on time-frequency characteristics [1]. To improve the correlation between similar stocks in the whole market, researchers also plan to further improve the prediction and generalization accuracy of the model by further considering more variables to find similar stocks [10]. In addition, considering that the stock market conditions of different countries are different, researchers also try to ensure that the proposed prediction model can adapt to the market environment under other policies [8].

VI. Conclusion

In this review paper, three main hybrid models combined with a deep learning approach to predict the stock price in the financial market have been introduced and analysed. There are also some limitations should not be ignored. Firstly, most of the prediction is based on a Chinese financial market background which may not be universal to all the stock markets. Additionally, except for financial news, the data source can also be collected on any other social medium, such as Twitter or Facebook. Finally, investors' sentiment may not be the only influential factor that has an impact on the stock price. In other words, some other factors can also be considered and analyzed, such as culture and international situation. Only more comprehensive ideas and repeated construction of models, the stock price predictive power will be stronger and forecasts can be realized sooner.

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