Designing a combined Markov-Bayesian model in order to predict stock prices in the stock exchange

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<th>ARTICLE INFO</th>
<th>ABSTRACT</th>
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<td>Received: 19 February 2023</td>
<td>Investing in shares offered on the stock exchange is one of the most profitable options in the capital market. The stock market has a non-linear and chaotic system that is influenced by political, economic, and psychological conditions. Forecasting time series, such as stock price forecasting, is one of the most important problems in the field of economics and finance because the data is unstable and has many variables that are influenced by many factors. There are many ways to predict stock prices. Non-linear intelligent systems such as artificial neural networks, fuzzy neural networks, and genetic algorithms can be used to predict stock prices. In this research, a hybrid system based on Bayesian networks and the Markov model is proposed to predict the daily trend of the stock market. Bayesian networks are used to specify relationships between variables in forecasting. Finally, the Markov model is used to predict the market trend in the sets extracted from the Bayesian network. The evaluation criteria in the proposed system show the high efficiency of this method.</td>
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<td>Reviewed: 11 March 2023</td>
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<td>Revised: 5 April 2023</td>
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<td>Accept: 1 May 2023</td>
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Keywords: Stock price, Bayesian networks, Markov model, Stock exchange

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1. Introduction

In the stock markets, there is a wide range of investors in terms of occupation, education, and experience. According to their expertise, each group chooses certain methods to predict the fluctuation of prices in the stock market and buy and sell stocks. The stock price can be changed at any moment due to changes in market supply and demand. Due to its high returns, the stock market is always considered one of the most popular areas of investment. However, some effective factors in the stock market have made the behavior of this market unpredictable. A market trend is a meaningful price movement in a certain time frame. Trends can be upward, downward or neutral. In an upward trend, the price tends to strengthen and rise more than it tends to weaken. In the downward trend, the price tends to weaken and decrease more than it tends to strengthen. The neutral trend expresses the equal power of buyers and sellers at a particular time \[1\].

If the number of buyers of a share is more than the number of its sellers, that is, the demand for buying a share is more than its supply for sale, the price of that share increases and vice versa. It is very easy to understand supply and demand and the resulting price changes. But what is difficult is to understand what leads to the changes in supply and demand in the stock market and causes some to become buyers or buyers of a particular share and others to turn away or sell it. Various theories have been formed to explain this behavior. Until now, many models have been presented using various tools and techniques to predict the market trend. Due to the fact that the correct forecasting of stock changes can lead to significant profits, it is very important to provide a model for intelligent forecasting of the stock market \[2\].

Forecasting stock price change is considered a challenging activity in financial time series forecasting. A correct prediction of stock price changes can bring a lot of profit to investors. Due to the complexity of stock market data, it is very difficult to develop efficient models for forecasting. Among the most recent fields in this regard is the use of neural networks to predict stock price behavior \[3\]. Advances in the field of artificial intelligence and machine learning, especially in the field of evolutionary computing, have not only enabled us to analyze data more effectively but also made it possible to use them to understand any underlying pattern of financial markets \[4\].

Different theories have been proposed regarding stock market evaluation and forecasting in organized markets. At the beginning of the 20th century, a group of experts with experience in evaluating securities firmly believed that it is possible to provide a picture for predicting the future price of stocks through the study and analysis of the historical trend of stock price changes. More scientific studies, emphasizing the accurate identification of stock price behavior, led to the trend toward stock price evaluation models. At first, the theory of random steps was proposed as a starting point for determining stock price behavior. Then attention was paid to the characteristics and structure of the capital market, and the results of these studies and investigations led to the hypothesis of an efficient capital market. This hypothesis was noticed by scientific circles because of its special composition \[5\]. With these theories, among the techniques that gained great importance were intelligent systems; Because assuming the linearity of the market structure, many models can be easily designed. However, it is very difficult to fully show the behavior of complex systems such as the capital market in a modern economic system in a set of simple and linear equations \[6\].

The purpose of this article is to provide a model to improve the prediction of stock market fluctuations. In this research, it has been assumed that only the internal factors of the stock market affect it, and the effect of external factors and external stimuli has been neglected. In the second part,
the literature review is presented. In the third part, the requirements of the proposed model are presented and the model is also presented. In the fourth part, we evaluate the results of the implementation of this model, and finally, in the fifth part, the conclusion will be presented.

2. Literature Review

Investment and accumulation of capital have played a significant role in the economic development of the country. The importance of this factor and its effective role can be clearly seen in the system of countries with a capitalist system. Undoubtedly, the stock market is one of the most suitable places to attract small capital and use them for the growth of a company, on a macro level, and also for the personal growth of the investor. Since the purpose and definition of investment is to postpone consumption for more and better consumption in the future; People expect to get their expected profit by investing. Therefore, the most important thing in this field is to buy a share at a low price and sell it at a higher price. It means stock price prediction. Since the opening of stock markets, there has always been the idea to predict stock prices with the help of a method, and in this way, hardware and software, different financial analyzes, and the like were invented and used [7].

By investing in the stock market, investors expect to achieve their expected profit, in this way, by buying a share at a low price and selling it at a higher price, they seek to gain profit, which requires price prediction and stock price prediction is one of the important tools for investment [8]. It is necessary to have the right information about the stock market, stock price changes, and influencing factors to gain profit. Identifying the influencing factors and their impact on the stock market by experts requires strong technical knowledge and analysis, which is not easily possible. Therefore, forecasting the stock price, which is a process over time (time series), is accompanied by errors due to the lack of knowledge of all factors and their effectiveness with traditional methods. Therefore, stock price forecasting is an important issue in which investors need powerful and reliable tools to forecast stock prices [9].

Many internal and external factors can affect people's buying process in the stock market and capital market, which include economic, political, and cultural factors. Also, internal factors such as biohythmic factors, stock market indices, indicators, inherent analytical power, acquiring the image of shareholders, matching the mental image of the buyer and the real image of the company, the level of risk tolerance, and the level of self-confidence [10]. Measuring these factors can lead to a more accurate understanding of investors' behavior. As a result, this causes the growth and development of the stock exchange and the country's economy. In this research, we examine some internal factors affecting the stock market. The correlation coefficient is one of the criteria used to determine the correlation of two variables used in this study. In this research, the influencing factors on the stock market are divided into two general categories: technical indicators and stock market indicators [11].

In recent years, many researches have been done regarding the prediction of stock prices in the Bose market. Gupta et al. [12] have used hidden Markov model to predict tomorrow's closing stock price. The proposed model is Map HMM, which predicts the maximum probability of the next day's price. Abhishek et al. [13] have used artificial neural networks to predict stocks. In this method, forward-looking architecture and Microsoft stock in 2011 and later have been used. Wang et al. [14] used dynamic Bayesian graphs to predict stock market trends. Time series are obtained by evaluating the relationships obtained from the Bayesian graph so that when the graph becomes stable, the stock market has a stable trend. ElAal et al. [15] have predicted the trend of the Egyptian market using neural networks and fuzzy logic. In this method, neural network functions such as classification were
In order to increase the predictability of the stock model, Lee et al. [16] modeled the stock return as a combination of discrete Markov chain and Gaussian chain. Turner et al. [17] investigated various models in which the variance of portfolio excess returns depends on a state variable generated by a first-order Markov process. Therefore, forecasting the stock market trend is still one of the fields of interest for researchers.

3. Research Methodology

The framework of the proposed model is based on Bayesian networks and the Markov model. This framework includes three general steps. The first stage includes the steps of data preparation, the second stage includes the steps of extracting relevant features, and the third stage includes how to achieve the prediction of the future price trend. In the first step, the correlation coefficient of the available features with the desired stock data for prediction is calculated and then the data is preprocessed. In the second step, the pre-processed data from the previous step are prepared for use in the Bayesian network and modeled by the Bayesian network, and the relationships between features are obtained by the conditional probability tables of the Bayesian network. In the third step, according to the connections of the previous step, the test data are modeled by the hidden Markov model, and then by returning to the Bayesian network, they are multiplied by the output probabilities of each node. Finally, with maximization, tomorrow’s stock price trend is predicted and compared with the actual value, and conclusions are made. The current research is applied in terms of purpose, and in terms of the method and method of data collection, it is a descriptive case study. In terms of subject matter, the present research is in the realm of financial forecasting issues, and in terms of time, it is in the form of an interval. The local aspect of the research is also considered the companies that are members of stock exchange and securities in Iran. The statistical population of this research is the companies accepted in the stock exchange.

The data is in Excel file format. The basis of the date of the data was considered the total index of the stock exchange in Iran. In this way, if there was no data on the date when the total index was available, for that price record yesterday, that is, we consider the price stability.

3.1. Formation of Bayesian network

A Bayesian network or Bayesian belief network is a non-circular directed graph that shows a set of variables and how they are related. In other words, a Bayesian network presents a sequence of variable states. These variables form the nodes of the Bayesian graph. The relationships between the variables are defined by the orientations of the edges of the graph. Each correlation is specified by the conditional probability table. After forming the Bayesian network according to the number of features, we form related sets, as follows: we start from the main data and select one of its children and add it to the set. In the next step, the desired feature plays the role of parent and we add the names of its children to the collection. In the next step, the children are placed in the role of the parent, and we continue in this way until we reach a dead end. Finally, we have as many related sets as the number of features that make up the Bayesian network. Bayesian networks correspond to Markov probabilities and say that a node is relatively independent of its parents. This feature of the Markov chain allows us to obtain the joint distribution on a smaller scale, so it is necessary to obtain (P(node|node(parents)) for all nodes. In larger networks, because the nodes It is smaller in proportion
to the size of the parent network, allowing us to significantly reduce the amount of computation required.

### 3.2. Markov model

After we have created related sets of variables, we now need to form a hidden Markov model on each set. These sets are a combination of features affecting a specific stock, which are placed in the hidden layer according to each set and make predictions according to the type of their connections. The number of hidden states for each model varies depending on the number of members of its set and is equal to N. So the size of the transfer matrix is N*N.

The number of different symbols used in the observation sequence is three because the data is divided into three groups: bullish, bearish, and stable. The classification of data is divided into these three categories with the advice of an expert in the stock market, and the class is determined every day according to the previous price. In this way, if today's price is higher than the previous day, the increasing class is considered, if it is lower, the decreasing class is considered, and if there is no change, the stability class is considered. The learning of the hidden Markov model of the proposed system was done with the Baum-Welch method, and the final conclusion was made using the forward method. The program is implemented in MATLAB environment.

After the probability of each class is obtained using the hidden Markov model, in the last step of the proposed system, we return to the conditional probability tables of the designed Bayesian network. In this way, we multiply each of the resulting probabilities by the input probability of the Bayesian network multiplied by that feature, which increases the effectiveness of the Bayesian network in the final result.

### 4. Data evaluation and analysis

First, we measure the performance of the proposed system with the clutter table. In this table, positive means increasing class and negative means decreasing class. It should be noted that the price stability class is not considered due to the small number of the statistical population. True Positive (TP) is equal to the number of days with maximum prices that are correctly predicted by the proposed system. True negative (TN) is equal to the number of days with a falling price that is correctly predicted by the system. False positive (FP) is equal to the number of days of rising prices that are wrongly predicted. False negative (FN) is equal to the number of days of falling that are wrongly predicted.

Accuracy, recall and F1-measure can be mentioned among the evaluation parameters of the classifier. The accuracy criterion is not a sufficient parameter to evaluate these systems, for this reason, we use another criterion called recall. The recall criterion, which is also referred to as the true positive rate, is a measure to measure the amount of correct positive answers predicted by the proposed system. The concept of this criterion means that, of the total number of incremental days in the test data set, how many percent are correctly predicted by the proposed system. F1-measure is a combination of precision and recall. This criterion specifies how far the proposed system has been successful in predicting correct and stable answers in terms of accuracy. Both precision and recall criteria are involved in the calculation of this criterion.

\[
\text{precision} = \frac{Tp}{(Tp + Fp)} \\
\text{Recall} = \frac{Tp}{(Tp + Fn)} \\
F1\text{- measure} = \frac{2 * \text{Recall} * \text{precision}}{(\text{Recall} + \text{precision})}
\]
Another important criterion in the evaluation can be called the accuracy criterion. The previously mentioned evaluation criteria evaluate the performance of the system from the point of view of the incremental class.

$$\textit{Accuracy} = \frac{(Tp + Tn)}{(Tp + Tn + Fp + Fn)}$$  (2)

Figures 1 to 3 show a set of prediction charts for the stocks of three companies in 2013. As mentioned in this research, the trend of changes is predicted. The vertical axis shows the trend changes and the horizontal axis shows the day. 217 days have been tested for each of the test sets. As can be seen from the graphs, the trend of changes in the two predicted sets and the actual set of the market have a harmonious behavior and their changes are consistent with each other.

Fig. 1. Stock trend of Company A.

Fig. 2. Stock trend of Company B.
The comparison is based on the location of the exchange, input data, combined methods and the degree of accuracy of the work output. The input data usually includes a combination of stock market indices and technical indicators related to industries and economic markets. The methods used in this research are a combination of data mining methods including genetic algorithm, MLP, SVR, etc. The comparison between the method presented in this article and other similar researches is summarized in Table (1).

### Table 1. Comparison of the results of the proposed model with previous works.

<table>
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<th>The best percentage of accuracy</th>
<th>Algorithm</th>
<th>Input data</th>
<th>Stock market</th>
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<td>80.24</td>
<td>Cart, Rep Tree, LAD Tree, …</td>
<td>44 financial ratios and Fundamental index</td>
<td>Iran</td>
</tr>
<tr>
<td>79.1</td>
<td>DTNB, BF Tree, LAD Tree, …</td>
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</tr>
<tr>
<td>85.25</td>
<td>BN-HMM</td>
<td>6 technical indexes and 22 indicators</td>
<td>Iran</td>
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### 5. Conclusion

In this research, a model based on Bayesian networks and hidden Markov model is proposed for daily forecasting of the Iranian stock market trend. At first, with the correlation coefficient of the stock market indexes and the desired stocks, 6 indexes are selected for specific prediction and also 20 indexes are calculated on the desired stock. 20 variables enter the Bayesian network and are modeled by this network. In this way, by creating a Bayesian network on the influential variables, the relationships between them were extracted and entered into the hidden Markov model. In the last step, the input probabilities to each branch in the designed Bayesian network are multiplied by the probabilities of the same output variable from the hidden Markov model.

The effectiveness of the proposed model was tested on the shares of three selected companies that have been active in the Iranian bus market, and the results with an accuracy percentage of 55.24 were obtained. As mentioned, we were able to predict the changes in the Iranian stock market using a combined method. The results showed that the use of technical indicators in predicting the trend of stock market changes and extracting related features using the Bayesian network and forecasting using the Markov model can be desirable. In this article, we were able to reduce the number of
effective features in forecasting, which leads to reducing the number of calculations, in line with the goal of this work, which was to predict the trend of stock prices in the Iranian stock market with high accuracy. In future works, it is possible to examine the impact of fluctuations in the global dollar and gold on the domestic market.

**Funding**

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

**Conflicts of Interest**

The author declares no conflict of interest related to this publication.

**References**


