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Modelling a System for Intelligent Forecasting of Trading on Stock Exchanges

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ABSTRACT The article highlights the reasons for changes in the price quotations of financial assets on stock exchanges. The article models the process of a situation when a trader fixes the period of holding his trading position. It defines periods of buying and selling and, taking into account that high-frequency stock trading on ultra-short intervals shows low profitability, introduces an important condition that allows a stock trader to freely open and close trading positions during the entire period of buying and selling with consideration of the proposed restrictions. The article offers modelling of the trader's strategy of carrying out trading actions aimed at maximisation of profit. Taking into account the liquidity constraints and quantitative limitations for trading orders, the article proposes to determine the optimal high-frequency trading strategy for buying and selling by a trader, which can be formulated as the task of minimising the cost of trading orders. Based on the number of available exchange trade orders and the values relative to the respective trade order at specific moments, determining the optimal high-frequency trading strategy for buying and selling a trader can be reduced to solving a simple cost minimisation problem under the given conditions of liquidity constraints for each trade order, completion of the trading portfolio without active positions before the end of the period and the total number of exchange buy and sell transactions. The key phases in building the structure on which the stock trading strategy itself is based are described. The need to determine what data will be entered into the algorithm of the artificial neural network based on the input data and to determine which algorithm will be used for a particular task is established. The structure of the software model of the system for intelligent forecasting of trading on stock exchanges is designed. The complex of the automated trading system includes the development of a graphical display of quotes and a tool for visual analysis. At the same time, information about proven trading strategies can be stored in a database that can be added and deleted by traders in the developed intelligent system for forecasting trading on stock exchanges.

KEYWORDS мodels, stock exchanges, trading strategy, artificial neural network algorithms, intelligent forecasting systems.

I. INTRODUCTION

The active use of information technology in the activities of various enterprises, regardless of their form of ownership, is becoming a standard. The classic way of conducting trading operations between brokers on a trading floor is gradually losing its relevance in favour of electronic trading via the network [1-3], which is carried out by people or automated trading systems. Thus, any individual can invest in shares traded on a stock exchange using his or her own computer. This investor even has the ability to change his or her decision after a few minutes or hours and put the shares up for sale.

In one sense, this mechanism helps to maintain the high liquidity of shares of publicly listed companies. At the same time, it also allows as many shares from the respective issuers as possible to be listed on the exchange [4]. This usually does not affect the strategic decisions of public companies, as investors are interested in profits rather than control of a particular company.

In this context, large financial participants offer a service called Market Making. These market makers are obliged to provide buy and sell prices for all traded shares at any time during the trading session (to maintain two-way quotes), and in doing so, they assume a certain trading risk associated with more informed market makers, which may ultimately lead to significant financial losses.

The greatest challenge of this service is to determine the fair value of a financial asset relative to the investment period at a particular point in time. In effect, the price of the issuer's shares is determined as a consensus between buyers and sellers at a particular point in time. This price is formed on a financial asset because there are an equal number of buyers who expect it to rise and sellers who expect it to fall.

At the same time, the efficient market hypothesis assumes that no one can get a better price for a financial asset than the one determined by the market [5-7]. This idea is based on the assumption that there is no possibility of arbitrage [8]. In other words, when investors anticipate that the price of a particular financial asset will rise, they start buying that asset, which leads to an increase in its price through the mechanism of supply and demand.

Therefore, the price is set at a level that removes the benefit of any forecast or analysis. In this context, it is assumed that the price reflects fair value at all times because, in the event of a deviation, market participants will act in a direction that brings the price to a fair level. Even if this statement seems logical, it is not conclusive for at least two reasons:

1. There are times when the price may deviate from

fair value even if there are buyers and sellers who continually adjust the price to that level before each adjustment;

2. Although the efficient market hypothesis assumes that there are always enough market participants with "good enough" predictive power (in the context of determining a fair price consensus), this hypothesis has never been supported by any convincing evidence.

II. RESEARCH OBJECTIVE

Based on the developed and researched trading strategy models and algorithms, develop an intelligent system for forecasting trading on stock exchanges.

III. MODELLING THE STRATEGY OF EXCHANGE TRADING DYNAMICS FOR TRADERS

Considering the situation when a trader fixes the holding period of his trading position h equal to the buying and selling period m and taking into account that high-frequency stock trading on ultra-short intervals h shows low profitability, we introduce an important condition that allows a stock trader to open and close trading positions freely throughout the entire buying and selling period. It is important to note that trades on the stock exchange do not necessarily have to be executed at evenly distributed time intervals. Hence, holding periods h may have different durations and, on average, be shorter than the buying and selling periods m. In this context, we have to determine the optimal holding period h for a trader with a buy-and-hold strategy of high-frequency stock trading in order to increase the profitability of his strategy.

In addition, at the moment of time t (during the period of purchase and sale h), such a trader has information about the state of the exchange's order book at any moment of time t_i (where $t \le t_i \le t+h$). Thus, at the moment t of buying and selling, a trader has the opportunity to make various decisions on opening trading positions with the possibility of their execution at any time t_i. There are only two restrictions for a trader:

1. The number of shares in his trade orders should not exceed the available volume on the market;

2. He should be ready to close the opened trading positions before the time $t+h$.

To determine the average optimal period for holding a trading position, it is necessary to analyse a trader's buying and selling strategy based on the dynamics of trade orders in the order book. It is assumed that within the framework of this strategy, a trader performs trading actions aimed at maximising his profit.

For this purpose, let us introduce the concept δv (for $i > 0$, where $\delta v_i = v_i - v_{i-1}$), which is a vector of all transactions (trade orders) to be executed within this strategy of high-frequency stock trading, where v – is the value of these transactions.

It can be assumed that the main types of transaction costs, such as exchange and brokerage fees, as well as the price spread (Bid Ask spread), can be described by a linear behavioural model and determined by a certain coefficient λ. After that, we can calculate the final financial result U_T for buying and selling by a trader using the stock exchange high-frequency trading strategy v. According to the approach [9-11] based on transactions and stock prices, it can be determined as follows:

$$U_T(\delta v) = \sum_{i=0}^{T} -\delta v_i p_i + p_T \sum_{i=0}^{T} \delta v_i - \lambda \sum_{i=0}^{T} \left| \delta v_i p_i \right| . \quad (1)$$

When trading only the best available orders in the order book, some notation can be simplified by typing:

p_{bcp} – the best purchase price on the exchange;

p_{bcpr} – the best selling price on the stock exchange;

v_i^+ – a trade order to buy on an exchange;

v_i^- – a trade order for sale on an exchange;

$bcpQ$ – the number of shares to be purchased;

$bcprQ$ – number of shares for sale.

Taking into account liquidity constraints and quantitative limitations for trading orders, determining the optimal high-frequency trading strategy for a trader's buying and selling can be formulated as a problem of minimising the cost of trading orders $J_\lambda(\delta v)$ using the approach presented in [11]:

$$J_\lambda(\delta v) = \sum_{i=0}^{T} \left(\delta v_i^+ p_{bcpr_i} + \delta v_i^- p_{bcp_i} \right) + \\ + \lambda \sum_{i=0}^{T} \left(\delta v_i^+ p_{bcpr_i} - \delta v_i^- p_{bcp_i} \right) \quad (2)$$

under the conditions:

- liquidity constraints ($-bcpQ_i \le \delta v_i^- \le 0$);
- liquidity constraints ($0 \le \delta v_i^+ \le bcprQ_i$);
- "empty" trading portfolio, i.e. closing all trading positions at the end of the period $T\left(\sum_{i=0}^{T} \delta v_i = 0\right)$;
- total number of exchange transactions ($\delta v_i = \delta v_i^0 + \delta v_i^+$);
- trade restriction ($z_{\min} \le v_i \le z_{\max}$), where $z_{\min}$ – minimum application, $z_{\max}$ – maximum application.

Denoting K as the number of available exchange trade orders and x_i^j as the value of x, relative to the corresponding trade order j at the moment i, determining the optimal high-frequency trading strategy for a trader's buying and selling can be reduced to solving a simple cost minimisation problem using the approach presented in the paper [11-14]:

$$J_\lambda(\delta v) = \sum_{i=0}^{T} \sum_{j=0}^{K-1} \left(\delta v_i^{j+} p_{bcpr_i^j} + \delta v_i^{j-} p_{bcp_i^j} \right) + \\ + \lambda \sum_{i=0}^{T} \sum_{j=0}^{K-1} \left(\delta v_i^{j+} p_{bcpr_i^j} - \delta v_i^{j-} p_{bcp_i^j} \right) \quad (3)$$

under the conditions:

- liquidity limit for each trade order j, where $-bcpQ_i^j \le \delta v_i^- \le 0$;

- liquidity limit for each trade order j, where $0 \le \delta v_i^{j+} \le bcprQ_i^j$;
- closing a trading portfolio with no active positions by the end of the period $T\left(\sum_{i-0}^{T=1}\delta v_i = 0\right)$;
- total number of exchange purchase transactions $\delta v_i^+ = \left(\sum_{j=0}^{K-1}\delta v_i^{j+}\right)$;
- total number of exchange sales transactions $\delta v_i^- = \left(\sum_{j=0}^{K-1}\delta v_i^{j-}\right)$;
- trade restriction ($z_{\min} \le v_i \le z_{\max}$).

The main goal of a stock trader who operates in all available markets is to maximise the profit from his trading operations [15-17]. The trading strategy used by him helps to reduce trading costs (increase profits) by meeting the liquidity requirements on the stock exchange at any given time. This task is linear and can be solved quite easily. Thus, all the necessary components are available to calculate the optimal average period of holding a trading position for such a high-frequency stock trader.

IV. ALGORITHM MODELS FOR INTELLIGENT SYSTEM DEVELOPMENT

The process of designing algorithms and system behaviour is defined at the stage of determining what algorithmic structure and function the programme code will perform [18-19]. This approach differs from the simple function of an algorithm, as the architecture provides an overall understanding of where specific algorithms are located in the system. This is especially important in many algorithmic trading robots, such as LiveAlgo, where the strategy is to use real quote data to find conditions for making trades. In the case of AlgoSignal, pre-prepared data from signals is used and decisions on a profitable position are made based on "auxiliary hints" from signals provided by real traders. This approach implies a primarily strategic approach to trading.

It is necessary to define that a trading strategy is a general plan covering a significant time period, and in our understanding, it is the achievement of profitability and certain results based on specific tactics, appropriate signals and algorithms. At the stage of defining the structure of algorithms, the architecture of an automated trading system is determined. So, in our case, there are two key phases in building the structure on which the trading strategy itself is based:

1. Obtaining initial data – creating algorithms for artificial neural networks that process price quotes;
2. Use of the obtained results – creation of specific actions with financial instruments, including the search for entry and exit points, placing orders based on the output of artificial neural network algorithms.

First, it is necessary to determine what data will be entered into the artificial neural network algorithm based on the input data. In our case, this means defining the input data as the values of closing prices from OHLC quotes. In Fig. 1 shows: a) a graphical display based on

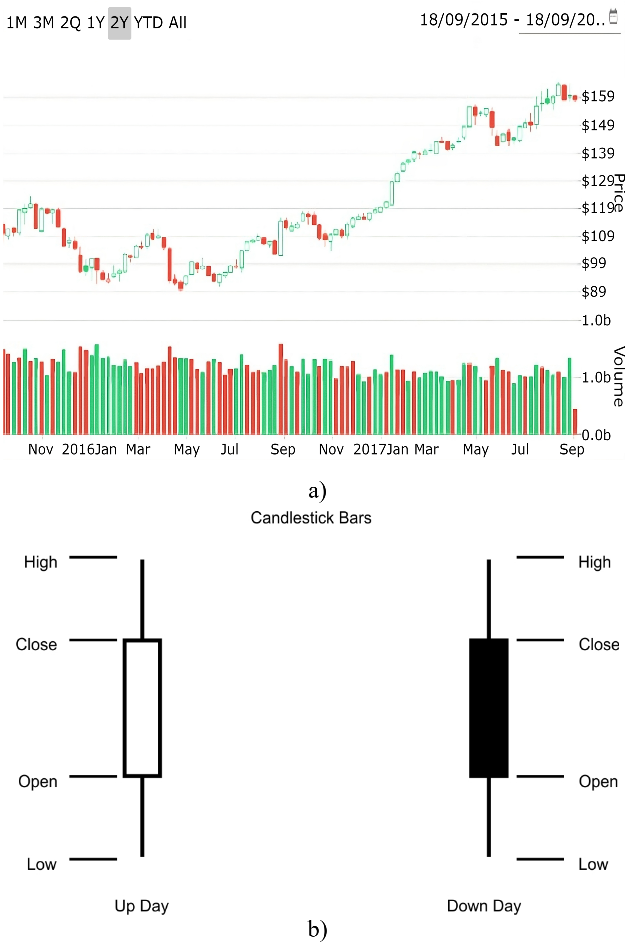

FIG. 1. Demonstration of: a) a graph based on OHLC values; b) the structure of OHLC values.

the values of Open, High, Low and Close prices; b) the structure of the Japanese candlestick, which represents the time period during which the trade took place.

Based on the results of the analysis, when a chart of quotes with a certain probability is available, the algorithm can be used to conduct trading operations, including the conclusion of transactions when appropriate market signals are detected.

First, we need to determine which algorithm we will use (Fig. 2):

1. RSI (Relative Strength Index) – this strategy is based on the expectation of an overbought signal during an uptrend;
2. EMA (Exponential Moving Average) – this strategy is based on the dominant trend in the market;
3. MACD (Moving Average Convergence / Divergence) – this strategy is based on closing a short position when the MACD crosses the zero line.

A trading strategy that has been tested can be saved in the database for further use. The structure of the developed software is shown in Fig. 3.

The software package of an automated trading system can include the development of a graphical display of quotes and a tool for visual analysis. Information about proven trading strategies can be stored in a database that can be added and deleted by traders. Fig. 4 shows an example of a chart with a visual analysis tool.

FIG. 2. Visual representation of strategy conditions based on a) RSI; b) EMA; c) MACD, respectively.

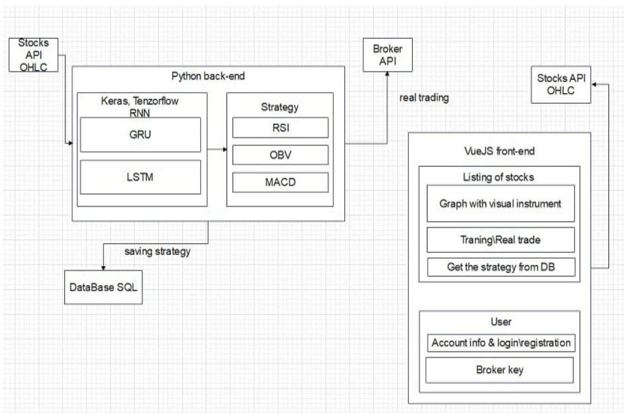

FIG. 3. Software structure of the system model.

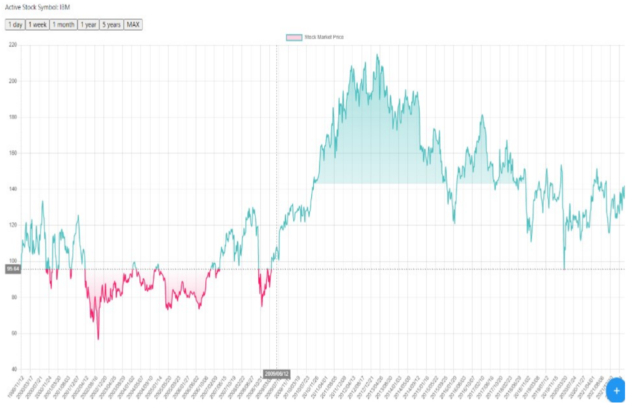

FIG. 4. Graphical representation of quotes with visual analysis tools within an automated trading system.

V. CONCLUSION

The article provides a reasonable analysis of the reasons for changes in price quotations of financial assets on stock exchanges. The authors have also modelled a scenario in which a trader independently determines the time period for holding his trading positions. Given that high-frequency stock trading at very short time intervals can bring low profits, the article emphasises the importance of ensuring that a trader can freely open and close trading positions throughout the entire period of purchase and sale with mandatory compliance with restrictions.

The necessity of modelling the trader's strategy to maximise profit under the constraints, including liquidity and quantitative restrictions on trade orders, is noted. The task of minimising the cost of trading orders is set, taking into account the limited number of available exchange trading orders and their cost at specific moments of time.

The key stages of building the structure on which the stock exchange trading strategy is based are described in detail. Information is provided on the data used and the choice of an algorithm for an artificial neural network in the context of a specific task.

In addition, the article reveals the structure of the software model of the system for intelligent forecasting of trading on stock exchanges. In particular, the article emphasises the development of a graphical interface for displaying quotes and a tool for visual analysis, which increases the convenience and efficiency of the trader. In addition, it is possible to save information on proven trading strategies in a database that is available to traders for their use in an intelligent system for forecasting trading on stock exchanges.

AUTHOR CONTRIBUTIONS

D.U., Y.U. – conceptualization, methodology, investigation; D.U., M.K. – writing-original draft preparation; D.U. – software, validation, formal analysis, investigation, resources; D.U., Y.U., D.B. – writing-original draft preparation, visualization, supervision writing-review and editing.

COMPETING INTERESTS

The authors declare no conflict of interest.

REFERENCES

[1] Y. Touzani and K. Douzi, "An LSTM and GRU based trading strategy adapted to the Moroccan market - Journal of Big Data", SpringerOpen, [Online]. Available: https://journalofbigdata.springeropen.com/articles/10.1186/s40537-021-00512-z.

[2] J. Kuepper, "Day trading: The basics and how to get started", Investopedia, [Online]. Available: https://www.investopedia.com/articles/trading/05/011705.asp .

[3] N. V. Bugas and Y. O. Panchenko, "Analysis of factors influencing the formation of the assortment", The journal "Effective Economy" - a scientific professional publication on economics, [Online]. Available: http://www.economy.nayka.com.ua/?op=1&z=2482.

[4] V. V. Lypchuk, "Marketing analysis", Library of Ukrainian textbooks, [Online]. Available: https://westudents.com.ua/knigi/281-marketingoviy-analz-lipchuk-vv.html.

[5] W. E. Buffett, "Tilson funds", Tilson Funds, [Online]. Available: https://tilsonfunds.com/superinvestors.php.

[6] L. E. Greiner, "Evolution and revolution as organizations grow", Harvard Business Review, [Online]. Available: https://hbr.org/1998/05/evolution-and-revolution-as-organizations-grow.

[7] L. Bachelier, "Théorie de la spéculation", Numdam, [Online]. Available: http://www.numdam.org/item/ASENS_1900_3_17__21_0/.

[8] E. Sun, T. Kruse, and M. Yu, "High-frequency trading, liquidity, and execution cost" Ann. Operations Res., vol. 223, no. 1, pp. 403-432, 2013.

[9] A. Smith, "Fast money: The battle against the high frequency traders", The Guardian, [Online]. Available: https://www.theguardian.com/business/2014/jun/07/inside-murky-world-high-frequency-trading.

[10] O. Filipova, "Learning vue.js 2", Packt Subscription | Advance your knowledge in tech, [Online]. Available: https://subscription.packtpub.com/book/web-development/9781786469946/2/ch02lvl1sec18/mvvm-architectural-pattern.

[11] F. Abergel, A. Anane, A. Chakraborti, A. Jedidi, and I. Muni Toke, "Limit Order Books", Cambridge: Cambridge University Press, 2016.

[12] O. Velychko and L. Velychko, "Logistical modelling of managerial decisions in social and marketing business systems", J. Int. Stud., vol. 10, no. 3, pp. 206-219, 2017.

[13] M. Kearns, A. Kulesza, and Y. Nevmyvaka, "Empirical limitations on high-frequency trading profitability", Journal of Trading, vol. 5, no. 4, pp. 50-62, 2010.

[14] A. A. Kyrylenko and A. V. Lo, "Moore's Law vs. Murphy's Law: Algorithmic trading and its discontent", Journal of Economic Perspectives, vol. 27, no. 2, pp. 51-72, 2013.

[15] T. Hendershott, C. Jones, and A. Menkveld, "Does Algorithmic Trading Improve Liquidity?" The Journal of Finance, vol. 66, no. 1, pp. 1-31, 2011.

[16] A. Chakraborti, I. Toke, M. Patriarca, and F. Abergel, "Econophysics: Empirical Facts and Agent-Based Models", Quantitative Finance, vol. 11, no. 7, pp. 1013-1041, 2011.

[17] M. M. Koshevyi, "Current aspects of knowledge-intensive industries and knowledge-intensive sectors of the economy | Efficient economy №11 2011", The journal "Effective Economy" - a scientific professional publication on economics, [Online]. Available: http://www.economy.nayka.com.ua/?op=1&z=1179.

[18] Y. Touzani and K. Douzi, "An LSTM and GRU based trading strategy adapted to the Moroccan market - Journal of Big Data", SpringerOpen, [Online]. Available: https://journalofbigdata.springeropen.com/articles/10.1186/s40537-021-00512-z.

[19] B. Zheng, E. Moulines, and F. Abergel, "Price Jump Prediction in Limit Order Book," J. Math. Finance, vol. 3, no. 2, pp. 242-255, 2013.

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Моделювання системи інтелектуального прогнозування торгів на фондових біржах

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АНОТАЦІЯ У статті виділено причини змін котирування цін фінансових активів на фондових біржах. Змодельовано процес ситуації, коли трейдер фіксує період утримання своєї торгової позиції. Вона визначає періоди купівлі-продажу і враховуючи, що високочастотна біржова торгівля на надкоротких інтервалах виявляє низьку прибутковість введено важливу умову, що дозволяє біржовому трейдеру вільно відкривати та закривати торгові позиції протягом всього періоду купівлі-продажу із врахуванням запропонованих обмежень. Запропоновано моделювання стратегії трейдера по здійсненню торгових дій, що спрямовані на максимізацію прибутку. З урахуванням обмежень, пов'язаних із ліквідністю, та кількісних обмежень для торгових заявок запропоновано визначення оптимальної стратегії високочастотної торгівлі для купівлі-продажу трейдера, що можна сформулювати як завдання мінімізації витрат на торгові ордери. На основі кількості доступних біржових торгових заявок і значень відносно відповідної торгової заявки в конкретні моменти з метою визначення оптимальної стратегії високочастотної торгівлі для купівлі-продажу трейдера можна зводити до вирішення простої задачі мінімізації витрат при заданих умовах обмеження ліквідності для кожної торгової заявки, завершення торговельного портфеля без активних позицій до закінчення періоду та загальної кількості біржових угод з купівлі-продажу. Описано ключові фази в побудові структури, на якій базується сама стратегія торгівлі на біржі. Встановлено необхідність визначення, які саме дані будуть введені в алгоритм штучної нейромережі на основі вхідних даних та визначення, який алгоритм буде використовуватись для конкретної задачі. Спроектовано структуру програмного забезпечення моделі системи інтелектуального прогнозування торгів на фондових біржах. У комплексі автоматизованої торгівельної системи включено розробку графічного відображення котирувань та інструмент для візуального аналізу. При цьому інформація про перевірені торговельні стратегії може бути збережена в базі даних, що доступна для додавання та видалення трейдерами в розробленій інтелектуальній системі прогнозування торгів на фондових біржах.

КЛЮЧОВІ СЛОВА моделі, фондові біржі, торговельна стратегія, алгоритми штучних нейронних мереж, системи інтелектуального прогнозування.