INFORMATYKA EKONOMICZNA BUSINESS INFORMATICS 3(29) • 2013
ISSN 1507-3858

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CONSENSUS-BASED TRADING STRATEGY IN A-TRADER SYSTEM[1]

Abstract: The authors of this paper present an approach to trading strategy design for an A-Trader multi-agent system which supports investment decisions on the stock market. The functionalities of the system, and the main component, the Supervisor Agent, used as a strategy a consensus method to reduce the level of investment risk, are described. The consensus method allows the coordination of the work of agents, and on the basis of the decisions provided by the agents presents trading advice to the investor. The strategy has been tested on FOREX quotes, namely on the pair USD/PLN. The results of the research are described and the directions of the further development of the platform are provided in the conclusion.

Keywords: multi-agent systems, financial decisions, consensus method, A-Trader system.

1. Introduction

Generally, the algorithms used in stock trading decision support systems can be based on mathematics, statistics, economics and artificial intelligence [Barbosa, Belo 2010; Chan, Wk Wong 2011; Karjalainen 1999; LeBaron 2011; Dempster, Jones 2001; Korczak, Lipinski 2008]. Investing in financial instruments is always related to the occurrence of risk as the uncertainty of the future performance of investments. This uncertainty occurs due to links between the functioning of the capital market and factors such as the economic policy of the Government, the level of interest rates, exchange rates, or phases of the economic cycle.

A very important element of risk management is to measure these risks, to estimate the level of risk that is being taken in relation to the size of the capital which is at the disposal of the investor, as well as the investment limits. In general, the risk measures can be divided into three basic categories [Jajuga, Jajuga 2000]:

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– volatility measures (i.e. average deviation, average coefficient of variations),
– sensitivity measures (i.e. beta coefficient, delta coefficient),
– downside measures (i.e. Value at Risk).

In order to reduce the risk, diversification is applied, that is, investing in different types of instruments as well as various instruments of the same type. However, the diversity of investment reduces the risk of the instrument with the greatest level of risk, but on the other hand also lowers the expected investment rate of return. Another technique to reduce the level of risk is to take investment decisions with the use of multiple methods at the same time.

The aim of this paper is to present the trading strategy in a multi-agent system which avoids risky investment decisions due to the integration and cooperation of the agents. In the design of our system, called A-Trader, the accuracy of predictions, the orientation on online trading and the adaptability of the financial knowledge base to the changing market environment were all important requirements.

The paper is divided into three main sections. The first one presents the functional architecture of the system and the main component – Supervisor Agent. In the second, the consensus strategy used by the Supervisor Agent to reduce the level of investment risk is presented. The last part is a description of the results of the Supervisor strategy testing and performance analysis on the FOREX quotes, namely on the pair USD/PLN. In the conclusion, further developments of the A-Trader system are announced.

2. Multi-agent system – functions

The key ideas of A-Trader have been already detailed in our previous papers [Korczak et al. 2012; Korczak et al. 2013]. The key component of the system is the Supervisor (S). The main goal of this agent is to generate profitable trading advice that reduces the investment risk. The supervisor, by using different strategies, coordinates the computing on the basis of decisions generated by Basic and Intelligent agents, and provides the final decision to an investor. Figure 1 presents the general functional schema of A-Trader. A few strategies were developed in the system such as the consensus strategy, the rule-based strategy, and the evolution-based strategy.

The strategies operate on the following assumptions:

1. Cloud of computing agents – buy/sell decision agents, the intelligent programs, which, on the basis of the signals received from the Notification Agent, take the specified decision on buy/sell. Each agent has been implemented with a different method of computation and decision making. Buy/sell decision agents send the decisions to the Notification Agent.

2. The Supervisor Agent – functions on the basis of the strategies that allow the determination of the final decisions on the basis of separate decisions generated by individual agents (read from Notification Agent), which are to be presented to

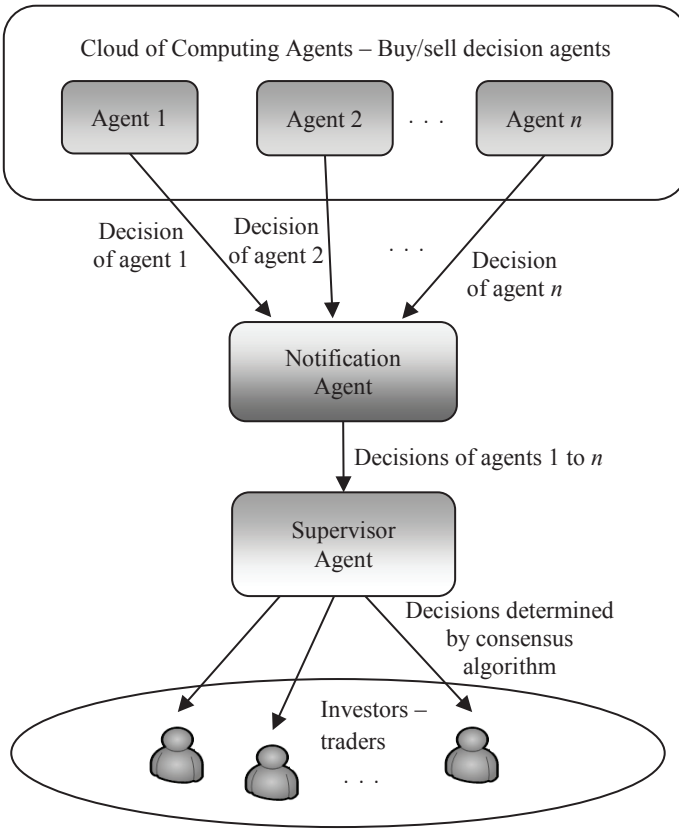

Figure 1. Functional schema of A-Trader

Source: own eleboration.

investors. As a consequence, it is possible to reduce the level of risk associated with investing in a financial instrument.

3. Investors – mostly traders who invest on financial markets, or bots (automatic traders).

The multi-agent system is composed of the agents being capable of generating independent decisions. These may be mutually consistent or completely contradictory decisions. Such mutually exclusive decisions are, for example, the open and close positions generated by two independent agents at the same time. The conflicts are resolved by the Supervisor, which observes the decisions of all the Cloud of Computing Agents and the Intelligent Agents, and assesses their effectiveness in investing and risk. The Supervisor determines which agents are taken into consideration when making an investment decision and whose advice is ignored based on the collected information.

The Supervisor may apply various strategies to generate the final trading decision. In the paper, the consensus method is detailed and tested. Consensus is defined as an agreement and originates from choice theory [Nguyen 2006; Zgrzywa 2007]. It is based on the existing solutions to a given problem, is very close to them, but does not have to be one of these solutions. The consensus in A-Trader is elaborated in three major stages. In the first stage is the structure of the set of financial decisions is carefully examined. In the second stage the distance functions among particular decisions are defined. The third stage consists of an elaboration of consensus decision having the minimal distance between the consensus and the individual decisions (according to different criteria) [Sobieska-Karpińska, Hernes 2012].

3. Supervisor-consensus strategy

The consensus method was implemented as one of the main strategies of the Supervisor. The consensus algorithm runs automatically after providing the decision advice by individual agents.

Each financial decision must be represented by using a concrete structure [Hernes 2011]. In our system, the financial decision consists of a trading position relating to a given quote, such as USD/PLN, USD/GBP, etc. The formal definition of this structure is the following:

Definition 1

Decision P about the finite set of financial instruments $E = \{e_1, e_2, \ldots, e_N\}$ is defined as a set:

$$P = \left\langle \left\{EW^{+}\right\}, \left\{EW^{\pm}\right\}, \left\{EW^{-}\right\}, Z, SP, DT \right\rangle, \tag{1}$$

where:

1) $EW^{\pm} = \left\langle e_o, pe_o \right\rangle, \left\langle e_q, pe_q \right\rangle, \ldots, \left\langle e_p, pe_p \right\rangle$.

Couple $\left\langle e_x, pe_x \right\rangle$, where: $e_x \in E$ and $pe_x \in [0,1]$ denote a financial instrument and this instrument's participation in set EW^{+}.

Financial instrument $e_x \in EW^{+}$ is denoted by e_x^{+}.

The set EW^{+} is called a positive set; in other words, it is a set of financial instruments about which the agent knows the decisions to buy, and the volume of this buying.

2) $EW^{\pm} = \left\langle e_r, pe_r \right\rangle, \left\langle e_s, pe_s \right\rangle, \ldots, \left\langle e_t, pe_t \right\rangle$.

Couple $\left\langle e_x, pe_x \right\rangle$, where: $e_x \in E$ and $pe_x \in [0,1]$ denote a financial instrument and this instrument's participation in set $EW^{\pm}$.

Financial instrument $e_x \in EW^{\pm}$ will be denoted by $e_x^{\pm}$.

The set $EW^{\pm}$ is called a neutral set. In other words, it is a set of financial instruments about which the agent does not know whether buy or sell. If these instruments are held by an investor, so that they should not be sold, or if they are not in possession of the investor, should not be bought by them.

3) $EW^{-} = \langle e_u, pe_u \rangle, \langle e_v, pe_v \rangle, \ldots, \langle e_w, pe_w \rangle$.

Couple $\langle e_x, pe_x \rangle$, where: $e_x \in E$ and $pe_x \in [0,1]$, denote the financial instrument and this instrument's participation in set EW^{-}.

Financial instrument $e_x \in EW^{-}$ will be denoted by e_x^{-}.

The set EW^{-} is called a negative set; in other words it is a set of financial instruments of which the agent knows that these elements should sell.

4) $Z \in [0,1]$ − predicted rate of return.

5) $SP \in [0,1]$ − degree of certainty of rate *Z*. It can be calculated on the basis of the level of risk related with the decision.

6) DT − date of decision.

A situation in which the structures of a decision in the system differ, or the values of their attributes are different, is called a knowledge conflict of these agents. This conflict results in the taking by agents of various, often contradictory decisions concerning buying and selling a financial instrument.

Consensus is determined on the basis of a decision generated by different agents working in the system. We call a set of such decisions a profile and define it as follows [Hernes, Nguyen 2007]:

Definition 2

E set of financial instruments $E = \{e_1, e_2, \ldots, e_N\}$ is given. In the case of A-Trader it is a set of pairs of currencies, e.g. USD/PLN, EUR/USD.

A profile $A = \{A^{(1)}, A^{(2)} \ldots, A^{(M)}\}$ is called a set of *M* decisions of a finite set of financial instruments *E*, such that:

$$A^{(1)} = \langle \{EW^{+}\}^{(1)}, \{EW^{\pm}\}^{(1)}, \{EW^{-}\}^{(1)}, Z^{(1)}, SP^{(1)}, DT^{(1)} \rangle$$

$$A^{(2)} = \langle \{EW^{+}\}^{(2)}, \{EW^{\pm}\}^{(2)}, \{EW^{-}\}^{(2)}, Z^{(2)}, SP^{(2)}, DT^{(2)} \rangle$$

.....

$$A^{(M)} = \langle \{EW^{+}\}^{(M)}, \{EW^{\pm}\}^{(M)}, \{EW^{-}\}^{(M)}, Z^{(M)}, SP^{(M)}, DT^{(M)} \rangle. \quad (2)$$

In the case of A-Trader, the profile is a set of decisions generated by Base Agents and Intelligent Agents. At the A-Trader system, the values *Z*, *SP* are provided by Base Agents and Intelligent Agents (e.g. by using statistical forecasting methods, or artificial intelligence methods) or by the Supervisor (e.g. on the basis of agent performance evaluation). The values *DT* are generated, by all agents, together with the trading decisions.

The consensus strategy is carried out according to the following algorithm:

Algorithm 1

Data: The profile $A = \{A^{(1)}, A^{(2)} .... A^{(M)}\}$ consists of M agents' decisions.

Result: Consensus $CON = \langle CON_+, CON_\pm, CON_-, CON_Z, CON_{SP}, CON_{DT} \rangle$ according to A. The consensus is a decision generated by the Supervisor Agent. This decision consists of the same attributes as the decision of the agents (e.g. CON_+ means consensus of the EW^+ set), but the values of these attributes differ.

Begin

1: $CON_+ = CON_\pm = CON_- = \varnothing, CON_Z = CON_{SP} = CON_{DT} = 0$

2: j:=1.

3: i:=+.

4: If $t_i(j) > M/2$ then $CON_i := CON_i \cup \{e_j\}$
Go to:6.

5: If i=+ then i:=±
If i=± then i:=-
If i=-, then Go to:6
Go to:4.

6: If $j<N$ then j:=j+1 Go to:3
If $j \geq N$ then Go to:7.

7: i:=Z.

8: Determine $pr(i)$.

9: $k_i^1 = (M+1)/2$, $k_i^2 = (M+2)/2$.

10: $k_i^1 \leq CON_i \leq k_i^2$.

11: If i=Z then i:=SP
If i:=SP then i:=DT
If i:=DT then End
Go to: 8.

End

The presented algorithm of consensus proposes a decision to the trader, who does not need to think about the choice of decision generated by Basic Agents and Intelligent Agents, which significantly reduces the time it takes to make a decision. It is important to note that the computational complexity of this algorithm is $O(3NM)$, where N denotes the number of quotation pairs and M denotes the number of agents belonging to the consensus profile.

Since a decision is taken on the basis of multiple agents' decisions, it also reduces the risk of taking this decision, because it eliminates the possibility to make an incorrect decision by one of the agents A-Trader system agents.

The verification of the Supervisor strategy is presented in the next section of the article.

4. Experiments

In the experiments, the currency quotations were extracted from the FOREX database. FOREX (Foreign Exchange Market) is one of the largest financial markets in the world for trading currencies. Currencies are traded against one another in pairs. Most of the foreign exchange transactions are highly speculative, this means that the traders buying or selling the currencies have no plan to deliver them at the end, but rather they were speculating on the changes of these currencies.

To evaluate the Supervisor trading performance using the pair USD/PLN, the USD/PLN quotation characterizes greater trend volatility than the EUR/USD quotation, therefore a higher rate of return can be generated. However, the level of investment risk is also higher.

In the evaluation the following assumptions have been imposed:

1. The minute-by-minute quotations USD/PLN are randomly selected, covering the following periods:

- 2013-08-27 hour: 04:08 to 2013-08-27 hour: 07:38,
- 2013-08-27 hour: 15:02 to 2013-08-28 hour: 09:01,
- 2013-08-30 hour: 15:38 to 2013-08-30 hour: 20:21.

For instance, Figure 2 presents a quotation of the pair USD/PLN in period III.

Figure 2. USD/PLN quotations

Source: own elaboration.

2. During verification, the Supervisor generates the decisions (signals buy-value: 1, sell-value: -1, remain unchanged-value: 0) generated by program agents, which operate on the basis of a combination of technical analysis indicators (i.e.. agent

no. 1 taking decisions on the basis of RSI, Stochastic Oscillator, MACD indicators combination, agent no. 2 – CCI, WILLIAMS, OBV, etc.). Due to the computational complexity and time constraints, the experiments were illustrated in the article by the Supervisor's signals generated by six agents.

3. Final Buy-Sell decisions are taken on the basis of the Supervisor's signals (Figure 3). It is assumed that the initial trader capital equals 10 000 PLN, and that the investment rate of return shall be calculated as the difference between the initial capital and the amount that the investor will have after the last sales in a given period. The rate of return is expressed in (PLN).

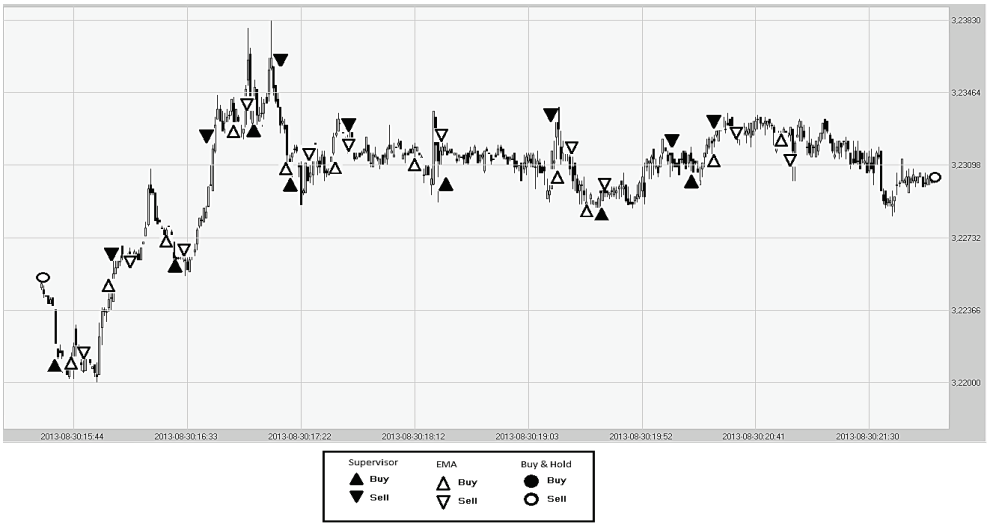

Figure 3. Decisions of Supervisor, Buy-and-Hold and EMA in the period III

Source: own elaboration.

4. No transaction costs are taken into consideration.

5. Money management – assume that in each transaction, the investor commits 100% of capital. The money management strategy can be set by the user. The investor invests every time 1000 PLN with the leverage rate[2] 10:1.

6. Performance evaluation is based on the following ratios:

a) the number of transactions,

b) gross profit,

c) gross loss,

[2] In trading, leverage is a general term for any technique to multiply gains and losses. Leverage exists when an investor achieves the right to a return on a capital base that exceeds the investment which the investor has personally contributed to the entity or instrument achieving a return [http://en.wikipedia.org/wiki/Leverage].

d) total profit,

e) the number of profitable transactions,

f) the number of profitable transactions in a row,

g) the number of unprofitable transactions in a row,

h) the average coefficient of variation is the ratio of the average deviation of the arithmetic average multiplied by 100% and is expressed as:

$$V = \frac{s}{|E(r)|} \cdot 100\%, \tag{3}$$

where: V – average coefficient of variation,
s – average deviation of the rate of return,
E(r) – arithmetic average of the rate of return.

i) Value at Risk – the measure known as value exposed to the risk − that is the maximum loss of the market value of the financial instrument possible to bear in a specific timeframe and at a given confidence level [Chan, Wk Wong 2011].

$$VaR = P*O*k, \tag{4}$$

where: P – the initial capital,
O – volatility − standard deviation of rates of return during the period,
k – the inverse of the standard normal cumulative distribution (assumed confidence level 95%, the value of k is 1,65).

7. The results obtained by the Supervisor have been compared with the passive strategy Buy-and-Hold and the benchmark using EMA.

The test was carried out in the following way:

1. On the basis of the quotation from the first period, each agent referred to when to buy and when to sell a currency USD/PLN.

2. Next, taking into consideration the decisions of all the agents, the consensus was determined.

3. The performance of the Supervisor and benchmarks Buy-and-Hold and EMA are reported.

4. Next, the steps 1 to 4 were repeated using the next periods of the financial time series.

5. In the final stage, the performance ratio values were calculated corresponding to rates of return resulting from all the decisions generated by the Supervisor, Buy-and-Hold and EMA strategies (not only of the final rates of return, but with all the rates of return calculated after each sale decision).

A comparison of final capital and rates of return obtained are shown in Table 1.

Summing up the results obtained through the use of the consensus method, in each period, a higher rate of return is shown compared with the decisions generated by the Buy-and-Hold and EMA. It should also be noted that the average rate of

Table 1. Comparison of final capital and rates of return

Period	Consensus		B & H		EMA	
	Rate of return [PLN]	Rate of return [%]	Rate of return [PLN]	Rate of return [%]	Rate of return [PLN]	Rate of return [%]
I.	234,00	0,023	–132,50	–0,013	60,00	0,006
II.	590,50	0,059	75,40	0,008	379,50	0,038
III.	298,00	0,030	260,70	0,026	161,30	0,016
Average	374,20	0,037	67,90	0,007	200,30	0,020

Source: own elaboration.

return of the Supervisor's decision is positive (profit), while the average rate of return of the Buy-and-Hold and EMA is a negative value (loss).

The performance analysis (Table 2) shows that the Supervisor generated a smaller number of transactions than using the EMA, but with the EMA, however, the gross profit from these transactions is higher than the gross profit generated by EMA and Buy-and-Hold.

Table 2. Results of performance analysis

Performance ratio	Supervisor – Consensus	B & H	EMA
Number of transactions,	23	3	38
Gross profit	1368,50 PLN	33,61 PLN	99,05 PLN
Gross loss	–246,00 PLN	–132,50 PLN	–389,70 PLN
Total profit	1122,50 PLN	203,60 PLN	600,80 PLN
Number of profitable transactions (%)	18 (78%)	2 (66%)	19 (50%)
Number of profitable transactions in row	6	1	5
Number of unprofitable transactions in row	1	1	4
Average coefficient of variation	8,33%	16,22%	19,27%
Value at Risk	266,50 PLN	316,30 PLN	375,40 PLN

Source: own eleboration.

At the same time, the gross loss generated by the Supervisor is relatively lower in comparison with the benchmarks. It should also be noted that the Supervisor conducted a 78% profitable transactions (Buy-and-Hold 66%, EMA 50%). The fact that the Supervisor does not generate a series of unprofitable transactions in a row is also important, but, for instance, the EMA generated such transactions. Analyzing the risk of decisions, it can be noticed that the use of consensus methods by the Supervisor allows the lowest level of risk investment. The value of Average

coefficient of variation equals 8.33%, while for Buy-and-Hold equals 16,22%, and instead for EMA 19,27%. The Value at Risk of decisions generated by the Supervisor was 266,50 PLN, which means that using the consensus method the trader can lose up to 266,50 PLN in a period of a few hours. Regarding Buy-and-Hold and EMA, this value was appropriately 316,30 and 375,40.

The value of Average coefficient of variation in the case USD/PLN quotation (8.33%) is higher than EUR/USD (6,29% − the results of the Supervisor strategy testing and performance analysis on the pair USD/PLN are presented in [Korczak, Hernes, Bac 2013]). Consequently, the value of loss can also be also higher in the USD/PLN quotation. Also the percentage of profitable transactions (78%) and the number of profitable transactions in a row (6 transactions) is lower in USD/PLN than in EUR/USD (appropriately 93.33% and 8 transactions).

These measures confirm the thesis that trading USD/PLN is more risky than trading EUR/USD.

The verification of using the consensus method by the Supervisor agent therefore suggested that the decisions supported by the A-Trader system are the decisions which allow the investor to get satisfactory investor results. It should be noted, of course, that the consensus method will not necessarily always get the highest rate of return. However it can be assumed that, as a general rule, it allows the investor to obtain a lower level of risk associated with the investment. Note that if an investor had to make the choice of which agent to "listen to", then, assuming that the probability of selection of the agents by the investor is the same, he/she could more often choose a decision (hint) of an agent that allows one to get a lower rate of return. Moreover, the evaluated agents using simple indicators are characterised by the large disparity in rates of return, confirming, for example, the value of the average coefficient of variation of EMA or Buy-and-Hold.

In conclusion, we can say that financial decisions generated by the consensus method allow to get a higher rate of return in comparison to benchmarks such as Buy-and-Hold and EMA, and get a faster determination of the decision than if the investor takes the decision himself/herself, among the decisions generated by the agents. Currently, due to the turbulent economic environment, investing in financial instruments must be carried out in close to real time. First and foremost however, the use of consensus algorithms by the Supervisor allows the investor to decrease the level of risk related to financial instrument investing. Therefore it also increases the level of usefulness of the decisions, and this can bring the user satisfying benefits.

It should be noted that the agents that were used in these experiments were built using technical analysis indicators, however, work on creating the agents applying other trading methods is in progress. For example the Traders Dynamic Index (it shows a current trend buy or sell opportunity in "double confirmed mode") or TrendLinearReg, (it works on the basis of assuming that the trend within N bars is a straight line, therefore it is possible to calculate the parameters of the equation of the straight line $y = bx + c$; the indicator calculates the inclination of the line,

characterized by the "b" coefficient or tangent of the angle of slope, using the linear regression on every bar).

It should also be stressed that the A-Trader system gives the possibility of implementing the agents using fundamental analysis, or behavioral analysis. Work on the extension and variety of the agents' knowledge is in progress.

5. Conclusions

The first attempts to implement a multi-agent environment have proved encouraging. The Supervisor decreased the investment risk by restricting the independent operations of more risk-taking agents for joint decisions of the entire environment. The cooperating agents made profitable decisions more frequently and close the loss-generating positions considerably earlier.

It should be stressed that the goal of multi-agent financial decision support systems, including the A-Trader system, is not only to maximize the rate of return on investment, but also to limit the level of risk associated with this investment. Taking into account the USD/PLN quotation dealt with in the article, it can be concluded that the level of risk is associated with, among other things, the fact that the financial situation of the złoty depends on the economic and political situation in Poland. Whereas the dollar depends on a variety of government regulations and the United States' engagement in the world economy. Consequently the level of risk is higher than in the EUR/USD quotation, because, among other things, the financial situation of the euro is more stable because it depends on the economic and political situations in many countries.

Of the experiment in the article, it can be concluded that the use by the Supervisor using the consensus method generates a lower level of investment risk. This can lead the investor to achieve a satisfactory investment rate of return.

It should be noted that the A-Trader allows the implementation of different, intelligent or behavioral Supervisor strategies. The strategy, based on agents' knowledge consistency evaluation, is under implementation. The described multi-agent system makes testing and validating these new algorithms easier by supplying the basic functionalities and data. It enables the concentration of work on constructing new Supervisor strategies without being concerned about the basic data and message supply mechanisms.

The A-Trader platform is now in the testing and expansion phase. The number and scope of the applied methods are being continuously expanded. New agents based on the recent methods are created. For example an agent, based on neural networks could be able to solve the problem of nonlinearity FOREX quotations, with their excellent ability to learn and generalize. It is perfectly suitable for detecting a similarity between the technical or fundamental situation of the individual quotations.

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CONSENSUS W STRATEGII INWESTYCYJNEJ W SYSTEMIE WIELOAGENTOWYM A-TRADER

Streszczenie: W artykule zaprezentowano sposób opracowania strategii inwestycyjnej w systemie wieloagentowym A-Trader. System ten umożliwia wspomaganie podejmowania decyzji inwestycyjnych na rynku finansowym. W tekście opisano zasady funkcjonowania systemu oraz scharakteryzowano jego główny component − Supervisor Agent, wykorzystujący w swojej strategii inwestowania metodę consensusu w celu obniżenia poziomu ryzyka inwestycyjnego. Metoda consensusu umożliwia koordynowanie funkcjonowania agentów oraz wyznaczanie, na podstawie decyzji wygenerowanych przez te agenty, ostatecznej decyzji prezentowanej następnie inwestorowi. Strategia ta została zweryfikowana z wykorzystaniem notowań rynku FOREX − pary USD/PLN. W końcowej części artykułu opisano rezultaty przeprowadzonych badań i kierunki rozwoju platformy A-Trader.

Słowa kluczowe: systemy wieloagentowe, decyzje finansowe, metoda consensusu, system A-Trader.