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MODEL OF DECISION-MAKING EXPERT SYSTEM ON FINANCIAL TIME SERIES

Model of expert system, using model indices of two indicators of time series for decision-making is suggested. The first of the indicators defines the trend of series growth, the second one – finds local extremes, using differential derivatives. Parameters of the first indicator are defined by means of digital filtration of input time series. Parameters of digital filter construction are optimized while operation of expert system in real time mode. Efficiency factor of decision-making is suggested, system operation efficiency is evaluated by this factor.

Key words: *time series, technical analysis, digital indicator, moving average, period, digital filter, efficiency.*

Actuality of the problem

Modeling of time series (TS) is used for description and forecast of various processes (variations of day temperatures, daily energy consumption). One of the typical examples of TS is financial time series (FTS). For their model elaboration such means of technical analysis (TA) as digital indicators (DI) are used. The closer to local minimum (maximum) the decision is made – the greater is the efficiency of time series forecast. The best indices are obtained as a result of several methods combination [1, 2].

Methods of using moving averages for decision-making are classical and well-known. While construction of greater part of existing DI simplified digital filters are used. Such approach was conditioned by non-sufficient computational facilities, used at the early stages of research dealing with digital filtration. Their main drawbacks are considerable phase delay and distortion of initial form of signal, resulting in the reduction of operation efficiency, due to omitting peak moments needed for decision-making [3].

In order to construct up-to-date indicators digital filters are to be used [1-3]. Ideal indicators must indicate signal amplitude and move with it in the same phase. Modeling of time series, using digital filtration enables to elaborate the model of decision-making system for the analysis of their behavior.

Application of digital filtration methods will help to improve digital indicators and to design new ones. Analysis and evaluation of indicators will allow to make decisions regarding determination of local extremums of time series and enhance the efficiency of expert system operation. Thus application of engineering analysis as component of intelligent technologies will help in forecasting of time series [4, 5].

The given research is aimed at elaboration of decision-making system, which will evaluate and analyze indices of model of two digital indicators. The suggested model is necessary due to existing problems dealing with accurate identification of local extremums moments.

It is necessary to improve the forecasting of digital filtration for construction of one of the indicators. Main task of the given research – is the construction of the model of decision-making system on time series. The goal of the research is enhancement of decision-making efficiency. The object of the research is decision-making process.

1. Construction of the indicator of low derivatives of time series

Discrete values are used for presentation of original values for computer processing. For determination of discrete process derivatives it is convenient to apply differential methods [6]. The first derivative can be found in the following way:

$$X'(t) = \frac{X(t) - X(t-T)}{T}, \qquad (1)$$

where $X'(t)$ – first derivative of TS at t moment, $X(t)$ – value of TS at t moment, $X(t-T)$ – value of TS at the moment, preceding t by the period, T – discretization period.

The second derivative can be determined analogously (1), knowing first derivatives $X'(t)$ and $X'(t-T)$:

$$X''(t) = \frac{X'(t) - X'(t-T)}{T}, \qquad (2)$$

where $X''(t)$ – second derivative of TS at t moment.

Model of TS motion decision-making can be constructed according evaluation of $X'(t)$ and $X''(t)$ by the following rules:

1) intensive growth of TS at simultaneous positive value of $X'(t)$ and $X''(t)$;

2) intensive drop of TS at simultaneous negative value of $X'(t)$ and $X''(t)$;

3) uncertain state of situation development at different signs of $X'(t)$ and $X''(t)$.

On the basis of the above-mentioned rules the model of TS motion character, which is based on evaluation of low derivatives is suggested:

$$\begin{cases} TS(t) = \max, X'(t) > 0 \cap X''(t) > 0; \\ TS(t) = \min, X'(t) < 0 \cap X''(t) < 0; \\ TS(t) = flat, X'(t) \cdot X''(t) \le 0, \end{cases} \qquad (3)$$

where $TS(t)$ – indicator value, max – reaching of local maximum, min – reaching of local minimum, $flat$ – uncertainty of extremums at t moment.

On the basis of developed model series corresponding to the values of the first and second derivatives of the series can be constructed. Graphic presentation of elaborated indicator model construction is shown in Fig. 1.

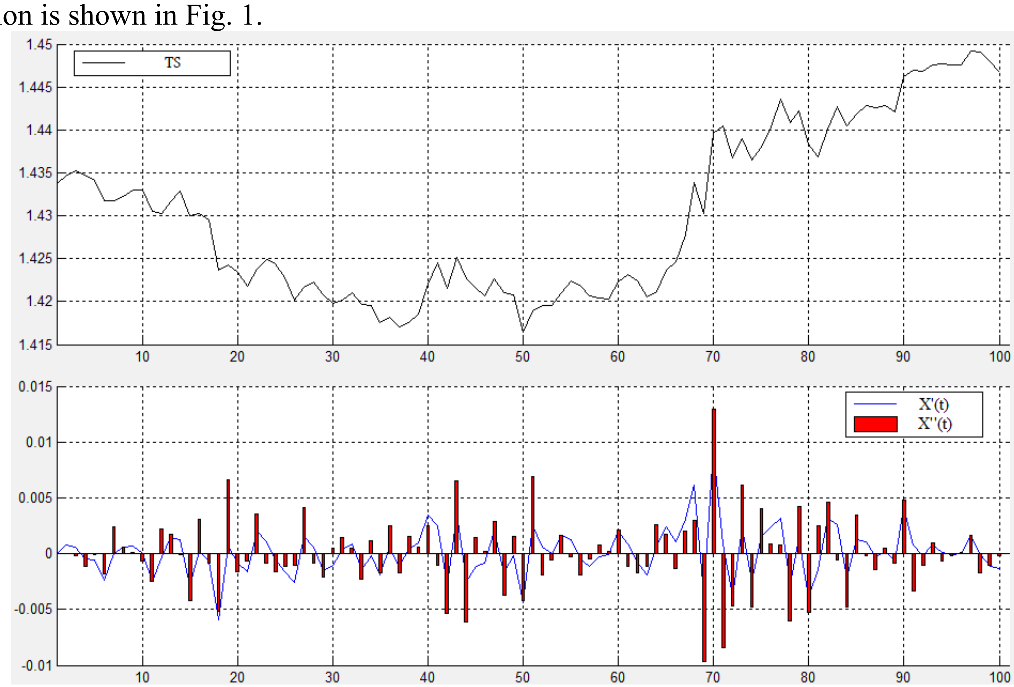

Fig. 1 – Indicator value of TS low derivatives

Elaborated model for the forecast of financial TS has one more peculiarity. For decision-making the important thing is quantitative comparison of the first derivative change during one and several tens of the last periods. Absolute increment allows to evaluate period value. In the denominator of the formulas (1) and (2) time is available. Period value can be evaluated in minutes. All large periods are multiple of a minute, and the next period is multiple to preceding one. Hence, for each of the periods average rate can be defined and compared with instantaneous. This will indicate absolute intensity of the rate change or acceleration.

2. Construction of indicator model designed for determination of TS motion trend

There exist already known indicators designed for determination of TS motion trend. They are based on definition of moving average of the series with different periods and comparison of their values [7, 8]. For definition of simple moving average of the series the formula (4) is used.

$$SMA(t) = \frac{X(t) + X(t - 1 \cdot T) + ... + X(t - k \cdot T)}{k}, \quad (4)$$

where $X(t)$ – value of time series during the last period, $X(t-k \cdot T)$ – value of TS during k periods ago, k – the order of the average.

Using the term order of the average, we mean the number of series members, used for determination of average. Other slidings are calculated applying similar formulas (smoothed, linearly-weighted, exponential slidings).

To improve the model of TS motion trend determination we will make use of the Fig. 2. It shows two moving averages with periods 5 (dashed – fast average) and 14 (solid line – slow average).

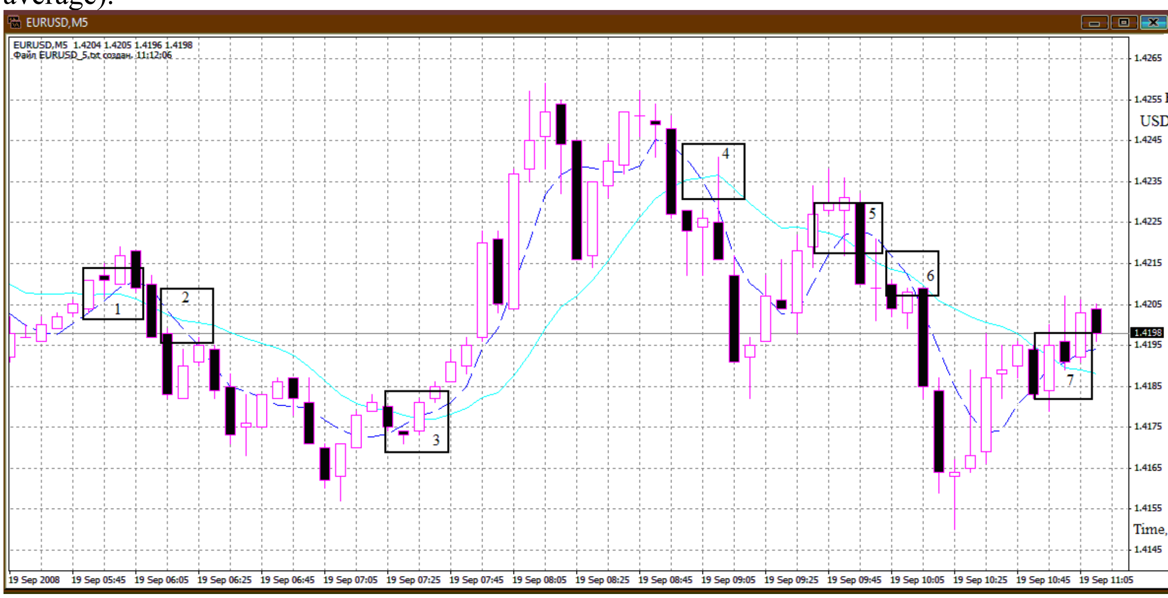

Fig. 2 – Usage of slidings for TS evaluation

For evaluation of TS motion trend it is necessary to make use of the difference between slow and fast slidings:

$$\nabla = FastSMA(i) - SlowSMA(i), \quad (5)$$

where $FastSMA(i)$ – fast sliding average, $SlowSMA(i)$ – slow sliding average.

When the difference changes sign from negative to positive – it is local minimum (moments for buying – № 1, 3, 5, 7). Change of the sign from positive to negative – it is designation of local maximum (moment for selling - № 2, 4, 6).

On the basis on the analysis performed the model of rules needed for determination of series motion trends can be formulated:

1) when fast sliding is greater than the slow one – series grows;
2) when fast sliding is less than slow one – series decreases;
3) in case of equality of fast and slow slidings – the transition moment occurs.

Model of evaluation of TS motion trend is presented by the formula (6).

$$\begin{cases} trend = up,\ fast(t) \geq slow(t); \\ trend = down,\ fast(t) < slow(t), \end{cases} \tag{6}$$

where $trend$ – index of model indicator in the last period, $up, down$ – increase or decrease of TS, $fastMA$ – fast indicator of TS motion, $slowMA$ – slow indicator of TS motion.

For qualitative construction of indicators we should make use of digital filtration, that reduces the influence of noise and cycles with great frequency on characteristics of fast and slow indicators.

Values of digital indicator, which are calculated by means of digital filter are determined:

$$Y(t) = b_0 \cdot X(t) + b_1 \cdot X(t-T)... - a_1 \cdot Y(t-T) - a_2 \cdot Y(t-2T) - ... \ , \tag{7}$$

where X – input time series, Y – output time series, a_i i b_i – set of weight coefficients of the filter.

Parameters a_i and b_i are determined from transfer function of the filter:

$$H(z) = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2} + ... + b_m z^{-m}}{a_0 + a_1 z^{-1} + a_2 z^{-2} + ... + a_n z^{-n}}, \tag{8}$$

For construction of transfer function three parameters are to be set, these parameters are seen from AFC, shown in Fig. 3:

1. Order of the filter.
2. Pulsation in passage band – formula 9 (normalized).

$$P = \frac{p}{s}. \tag{9}$$

3. Frequency of the cut – formula 10 (normalized).

$$F = \frac{c_1}{d_1}, \tag{10}$$

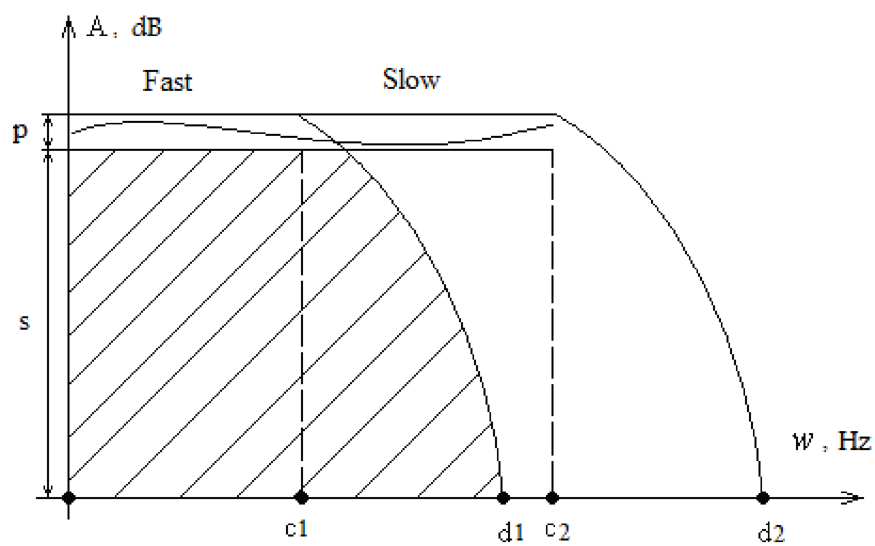

Fig. 3– AFC of filters for construction of fast and slow indicators

Selection of filter parameters in rather formalized procedure, but their constant values do not satisfy the condition of permanent behavior change of investigated filters. That is why it is necessary to elaborate algorithm of optimization parameters for construction of filter for fast indicator.

3. Optimization of low frequency filter parameters

Two parameters of low-frequency filter (LFF) are to be optimized – they are: frequency of cut and pulsation in the bandwidth [9]. Basic optimization involves fixation of parameters of one of two filters, used for construction of corresponding indicators. For variation the parameters of fast indicator filter were chosen, since the restrictions on minimum filtration frequency are imposed. Filter parameters are optimized by means of complete exhaustive search, with the set step of 0.01. In this case, 3D function is formed, optimized parameters being the arguments of this function. The value of pulsation and cut-off frequency at witch decision-making system shows highest efficiency will be considered optimal.

The structure of optimization algorithm is shown in Fig. 4. When optimization is completed, the efficiency function has the shape, shown in Fig. 5.

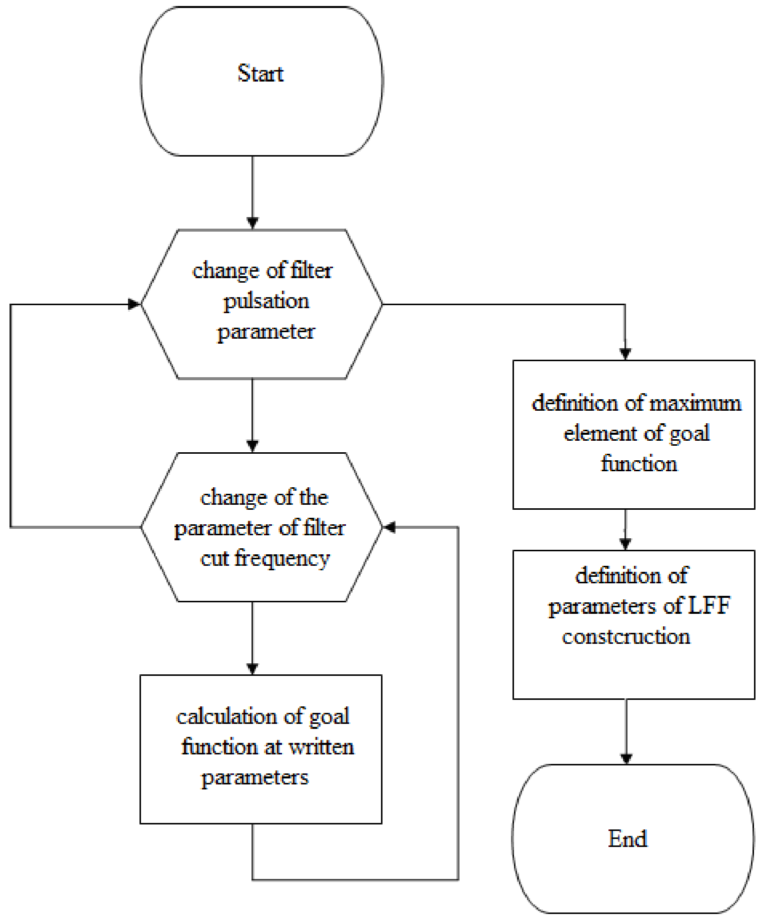

Fig. 4 – Algorithm of optimization of LFF parameters

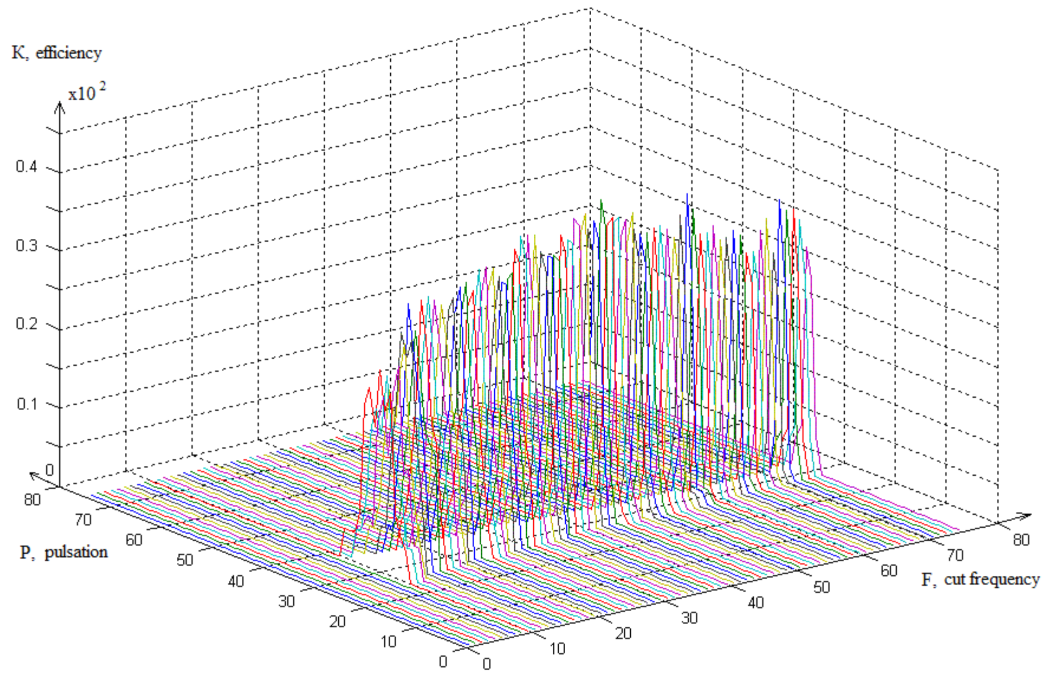

Fig. 5 – Efficiency function after optimization operation

Maximum element of efficiency function shows those parameters of digital filter at which time series behavior can be forecast in the most efficient way. After calculation of LFF parameters, its coefficients must be calculated and corresponding indicator is to be constructed.

To perform optimization, the parameter, according to which it will be performed to, must be determined.

4. Determination of the decision-making efficiency criterion

For determination of efficiency criterion we will use the formula of efficiency factor of any system or process:

$$K = \frac{N_1}{N_2} \cdot 100\% . \qquad (11)$$

In the formula (11) the value N_1 characterizes the obtained gain as a result of time series forecast. Value N_2 characterizes total growth of FTS [10, 11].

Formation of both values N_1 and N_2 will be carried out in accordance with the similar rules. The only difference is that value N_1 will indicate the real gain, obtained from decision-making system operation, and N_2 – gain, obtained from hypothetically possible correct forecast during chosen time interval [3].

The set of decision taken is determined by N_1:

$$N_1 = \sum_{i=1}^{n} (s_i - b_i) , \qquad (12)$$

where b_i – value of the series at the start of the forecast process, s_i – value of the series at the end of the forecast process, n – number of forecasts.

To determine the total motion of TS during the chosen time interval it is necessary to determine the value of N_2:

$$N_2 = \sum_{j=1}^{k} (|c_j - o_j|) , \qquad (13)$$

where c_i – price at the end of each discrete period, o_i – price at the beginning if the period, k – total number of periods of the chosen time interval for the forecast.

General criterion of decision-making efficiency will have the following form:

$$K = \frac{\sum_{i=1}^{n}(s_i - b_i)}{\sum_{j=1}^{k}(\left|c_j - o_j\right|)} \cdot 100\% . \qquad (14)$$

Maximum value the efficiency criterion can be achieved on condition of the exact forecasts during investigated period of time. Negative value will indicate the advantage of wrong forecasts. The greater value criterion achieves while following the indicators of the chosen strategy, the higher the efficiency of the strategy is [7, 10].

5. Construction of decision-making system model

Taking into account the developed methods of TS evaluation by means of the value of motion trend indicator , indicator of low derivatives, the model of decision-making system can be formed. Decisions regarding the finding of local maximum can be made in case of the following relation of indices:

$$fast(t) < slow(t) \cap X'(t) > 0 \cap X''(t) > 0 . \qquad (15)$$

All the indicators are described above. In case of such relation the system makes decision or recommendation regarding TS drop forecast.

Determination of local minimum is connected with such indices:

$$fast(t) > slow(t) \cap X'(t) < 0 \cap X''(t) < 0 . \qquad (16)$$

In case of such relation the decision regarding TS drop is made.

Last 6 possible situations, which are not included in (15) and (16) will not be signals for the system to take new decisions. Values of model indicators in this case will be the following:

$$\begin{aligned}
&fast(t) < slow(t) \cap X'(t) > 0 \cap X''(t) < 0 \cup \\
&fast(t) < slow(t) \cap X'(t) < 0 \cap X''(t) > 0 \cup \\
&fast(t) < slow(t) \cap X'(t) < 0 \cap X''(t) < 0 \cup \\
&fast(t) > slow(t) \cap X'(t) < 0 \cap X''(t) > 0 \cup \\
&fast(t) > slow(t) \cap X'(t) > 0 \cap X''(t) < 0 \cup \\
&fast(t) > slow(t) \cap X'(t) > 0 \cap X''(t) > 0.
\end{aligned} \qquad (17)$$

In this case the recommendations regarding TS movement in any direction should not be given [9].

Algorithm of decision-making model is shown in Fig. 6.

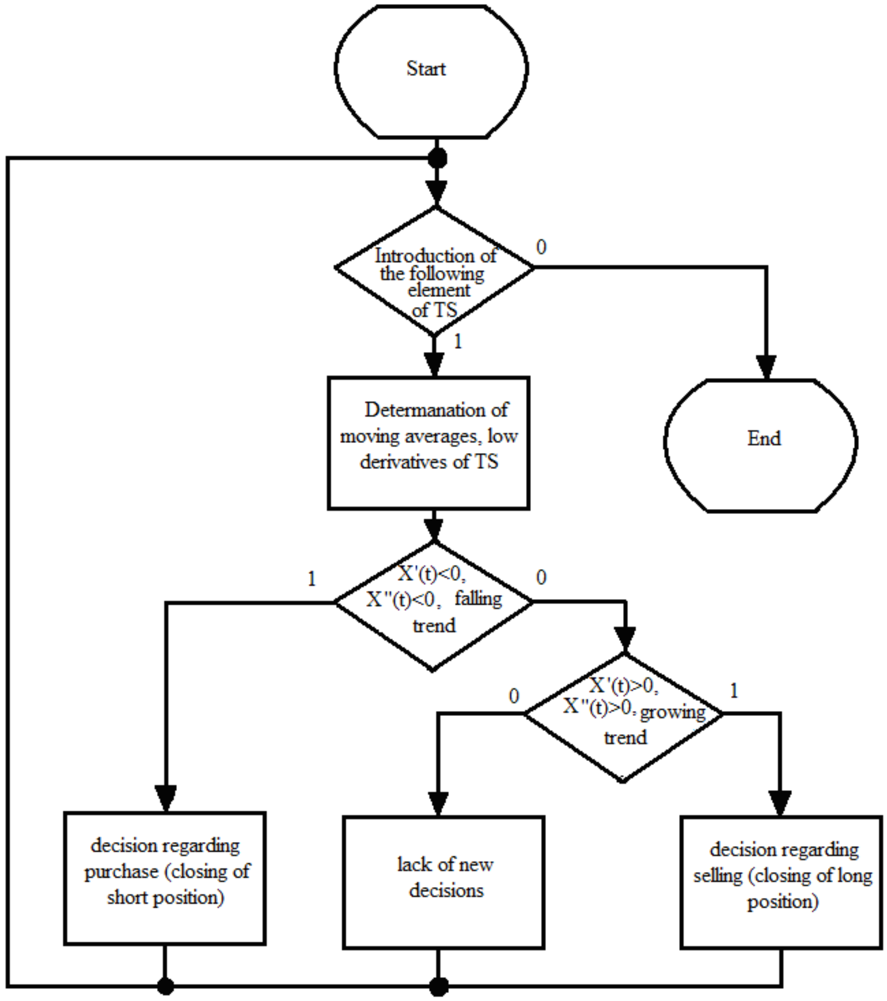

Fig. 6 – Algorithm of decision-making

The developed model is realized by means of an indicator in MATLAB environment. For construction of TS motion fast indicator the parameters of the filter were the following: pulsation w P = 0.34, cut-off frequency F = 0.15. System efficiency was 12.88%. After optimization filter parameters were: P =0.3 for pulsation and cut-off frequency F = 0.42. Efficiency of the system was 34.12%.

Graphic interpretation of model operation is shown in Fig 7.

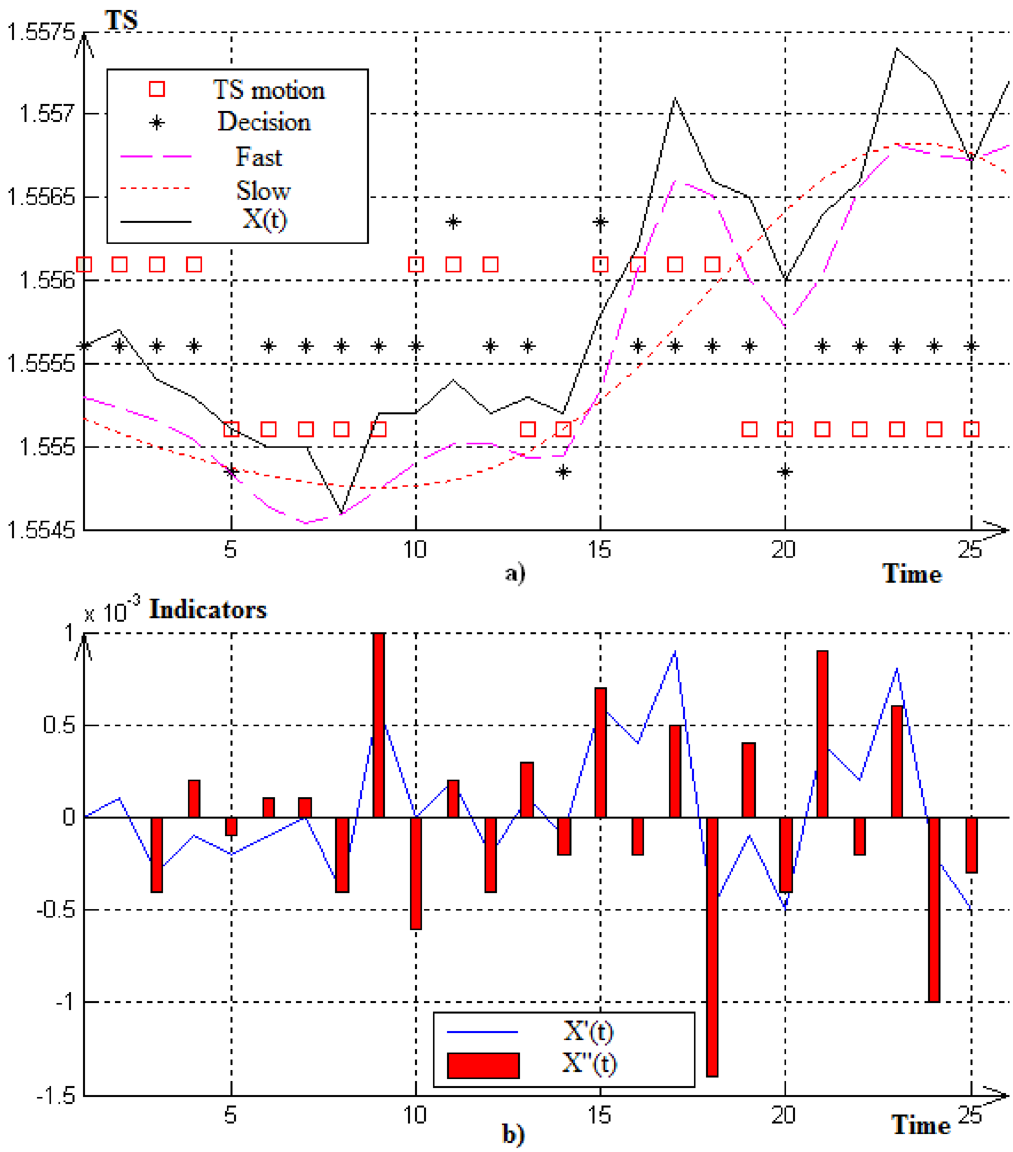

Fig. 7 – Illustration of indicator operation

In the part a) the value of closing price («X(t)», solid line) on 5 min graph is presented (25 periods are shown). Indicator of series motion direction is shown by squares and is constructed along the lines «Fast» and «Slow». Periods, when the trend falls, are shown by squares below middle line, and when the trend grows – above middle line. In part b) of the Fig. 7 rate (solid broken line) and acceleration (column diagram) of the time series shown. After the period number 5 when series motion direction indicates fall of the trend, and derivatives are negative, indicator shows minimum – buying on low price (1.5551). In the case of reverse value of TS motion and positive indicators of rate and acceleration it is recommended to sell on high price (local maximum 1.5554). Long position is closed (first buying then selling occurred). The profit is 3 points during 30 minutes of astronomic time. After the period 11 short position is open (selling), and after the period № 14 this position is closed, the profit is 2 point. If the indicator is connected with trade platform, the system will operate automatically. It should be noted, that the indicator showed positive results of operation during all periods without exception. The suggested indicator does not required analysis of graphs of smaller periods, because information processing and decision are made after formation of the values of current position.

Conclusions

Model of TS digital indicator based on digital filters is improved. The possibility of application of low frequency filter with different bandwidths is investigated. The important issue is mutual relation of TS, obtained by means of various filters.

Model of TS digital indicator, based on determination of low derivatives is elaborated. This approach allows to evaluate movement intensity and define extremums of the decision-making on time series.

Decision-making model, based on time series is elaborated. The model uses the combination of two indicators. One of them determines the trend of series motion, and the second indicator shows the approach of extremum. The elaborated model, unlike the existing ones, takes into consideration the behavior of time series in real time, which enabled to find and adjust the parameters of the model in order to enhance series forecast efficiency.

Efficiency factor of decision-making on financial time series is suggested, that enabled to evaluate the quality of decision-making system operation, based on constructed indicators. The elaborated efficiency factor provides the possibility to compare results of functioning of different strategies as well as the same strategy, but with different parameters.

Among the possible directions of further research we can distinguish the following:

1. Improvement of decision-making expert system model by means of increase of indices, being analyzed, and increase of accuracy of the moment of local minimum (maximum) determination.
2. Development of new models of digital indicators to determine decision-making risks and take them into account during expert system operation.
3. Improvement of the efficiency of algorithms intended for digital filters parameters optimization for construction of indicators due to determination of optimum relations of filter parameters while construction of moving averages and analysis time series signal spectrum.
4. Investigation of indicator parameters and decision-making system orders while taking faulty decisions and formation of restrictions regarding the usage of developed model.

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