IMPACT OF A DISCRETIZATION UNIT ON BINARY REPRESENTATION OF EXCHANGE RATE

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Abstract: *An exchange rate of a currency pair can be shown in binary representation. The algorithm of binarization depends on the conversion of an exchange rate represented by tick data into a corresponding binary string. Each increase of an exchange rate, by a given discretization unit, is attributed a binary value of 1. In turn, 0 is assigned to each exchange rate decrease. Properties and a character of exchange rate in binary representation, e.g. the impact of random fluctuations (noise), the level of interdependencies between current changes and historical data, depend on an assumed discretization unit. The research presents a statistic analysis of a currency pair exchange rate in a binary representation, for various discretization units. The analysis was conducted to test the possibility of using the binary representation to build prediction systems based on a state model for binary representation (SMBR). For the analysis tick data of AUD/NZD pair was used in the period of 2012-2016.*

Key words: *currency exchange market, technical analysis, investment decision support, exchange rate*

JEL codes: *C44, C02, F31, G10*

1. Introduction

Currency exchange rates (hereinafter referred to as currency rates or exchange rates) indicate a significant volatility (on average, currency rates change every few seconds), therefore, exchange rates are traditionally presented on all online broker's platforms in the form of candlestick charts. This particular data representation depends on the assumed time interval which is the given time for the construction of a single candlestick. Traditionally, the assumed values are 1, 5, 30 minutes, 1, 4 hours and 1, 7 days. Such a representation is commonly used to determine the values of required indicators and in visual methods of technical analysis of currency rates (Burgess, 2010; Schlossberg, 2006). The parameters of candlesticks charts that are dependent on given time interval can lead to significant interpretation problems. Candlestick representation results in information loss on an order and a number of changes covered by a candlestick chart. Therefore, the exchange rates modelling (especially in terms of construction of High Frequency Trading systems (HFT)) the binary presentation was introduced (Stasiak, 2016a). In such a representation each change of the currency rate, by the value of assumed discretization unit, is attributed a binary value, depending on the direction of the change. Such an approach eliminates those periods of time when no fluctuations in exchange rates occur, e.g. nights, but at the same time it retains the information on the direction and level of changes, which, for a potential investor, is essential. The accuracy of that probability depends on the assumed discretization unit. Basing on the binary representation, accompanied by dedicated models, for instance the state model for binary representation (SMBR) (Stasiak, 2016a) a probability of a future direction change of currency rates can be estimated.

The paper presents the influence of a size of an adopted discretization unit on the accuracy of implemented models basing on a binary representation of AUD/NZD exchange rates.

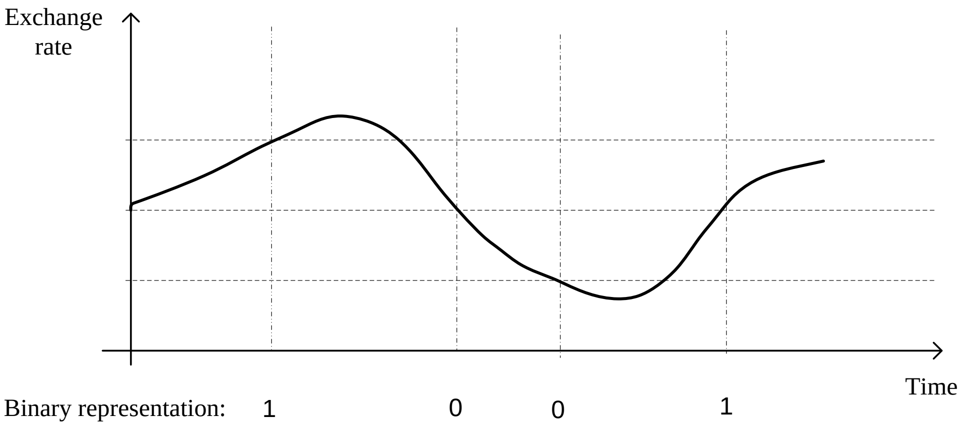
The article is arranged as follows: chapter 2 presents the assumptions and advantages of the binary representation of currency rates, chapter 3 describes SMBR, chapter 4 shows the results of the research on the influence of discretization unit on SMBR, in the view of creation of HFT systems. The last chapter discusses the vital results of the research.

2. Binary representation of exchange rates

Exchange rates are characterized by a high frequency of change in time. Exchange rates fluctuate, on average, every few seconds. Such a frequency makes the analysis of tick chart (which registers all changes) almost impossible. Also, incorporation of tick data in statistical analysis is ineffective due to a big number of data and the noise (a lot of small, random changes with a range of several pips) (Lo et al., 2000; Logue and Sweeney, 1977; Menkhoff and Taylor, 2007; Neely and Weller, 2011). Therefore, exchange rates are traditionally presented in the form of a candlestick chart. Each candlestick is represented by four parameters: opening price, closing price, maximum price and minimum price, in a given time. Candlestick charts depend on a so-called time frame, i.e. the time which is represented by a single candlestick. Traditionally, this time frame ranges from one minute to one day. Candlestick representation is commonly used by all broker's platforms (e.g. MetaTrader or JForex). Most of visual methods of technical analysis use candlestick charts (e.g. wave theory, chart patterns etc.). The parameters of such indicators as, for instance, Relative Strength Index (RSI) or Moving Average Convergence / Divergence (MACD) are also based on a single or several parameters of a candlestick (Murphy, 1999; Neely and Weller, 2011; Schlossberg, 2006; Yazdi and Lashkari, 2013). In case of scientific work concerning the implementation of neural networks for the prediction of exchange rates, also the candlestick charts are used (Jasemi, 2011).

To eliminate the loss of vital information in exchange rates presented by candlesticks, in (Stasiak, 2016a) a binary representation was introduced. The solutions which used a binary approach were already known in 1930s and were used for construction and analyses of the charts in so-called the Point and Figure Method (De Villiers, 1933). Unfortunately, this way of representation was superseded by candlestick charts. The basis of the binary representation is the discretisation of exchange rates due to an adopted discretisation unit. Figure 1 shows an example of a binary representation of exchange rates. This algorithm assigns the binary value equal zero (0) when the exchange rate falls, whereas in the case when the price increases, the algorithm assigns the binary value equal one (1) to that change. In case of price gaps, the algorithm examines which value would have been achieved and analyses the exchange rate regarding the first price following the gap. As a consequence of algorithm implementation, the exchange rate can be presented as a binary string. Using binary representation eliminates periods of time when no fluctuations in exchange rates occur (e.g. nights) but at the same time it retains the information on the direction and level of changes in times of increased activity of investors.

Fig. 1 Binary representation of exchange rates



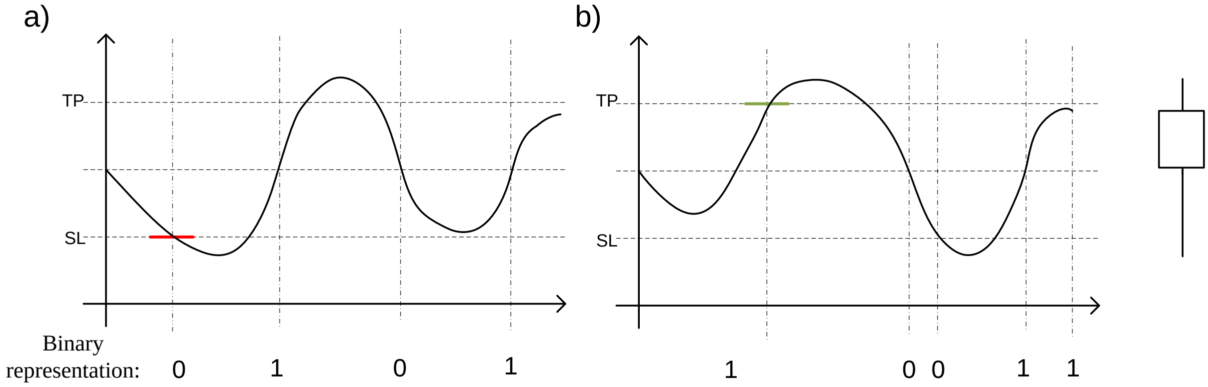
Source: Own elaboration

Exchange rates are characterized by a high frequency of change in time. During the night the exchange rate can change by several pips, however, during a presentation of vital macroeconomic data – e.g. new interest rates – the exchange rates can change by a few dozen pips within several seconds. Such a character of changes may lead to a "loss" of an important section of information on the direction and level of smaller changes, especially, when the tall candlestick lasts. This fact is significant in terms of HFT systems. Even the implementation of one-minute candlesticks (the most accurate candlesticks offered by broker's platforms) leads to a significant information loss on particular changes lasting less than a minute in times of the intensified activity of investors.

The loss of the data leads to the deterioration of modelling quality and consequently to results which are not credible.

Let us consider a HFT system including transactions in which the TP (Take Profit) and SL (Stop Loss) parameters are remote from the opening price by 15 pips. By implementing a candlestick analysis, in many cases, it is hard to tell whether a particular transaction resulted in a profit or a loss (which of the parameters – TP or SL – was reached first). Figure 2 shows two different runs of changes in exchange rates represented by the same candlestick. The first option will result in a profit, the latter in a loss.

Fig. 2 Two different runs of changes in exchange rate represented by the same candlestick



Source: Own elaboration

The binary representation can be used for construction of HFT systems. HFT systems enter into hundreds (or thousands) of transactions of a small range, which last just minutes or even seconds. The investor's profit is created due to a statistical advantage of profitable transactions over those that bring losses.

Let us consider a given binary representation. The assumption is that the entered transactions are those in which TP parameter equals a current price enlarged by a discretization unit, whereas SL equals a current price decreased by the discretisation unit. The probability of making a profit equals the appearance probability of '1' in binary representation. Similarly, in case of sale transaction, the profit equals the probability of '0' occurrence. Basing on models which allow the approximation of future direction of changes (e.g. State Model for Binary Representation – SMBR (Stasiak, 2016a), State Model for Binary-Time Representation – SMBTR (Stasiak, 2016b) and State Model for Binary-Wave Representation (Stasiak, 2017), it is possible to construct HFT systems characterised by a positive rate of returns.

Until recently the access to currency market was limited to professional investors. Due to the development of telecommunication and computer science in the past years, the number of participants grew rapidly (the development of broker's platforms, a decrease of required deposits). Technological changes also enabled a much faster process of transactions. The introduced broker's platforms, like MetaTrader 4 or JForex, enable placing and realisation of orders almost in real time (time is counted in milliseconds) and the possibility to enter hundreds of transactions of small range popularised HFT systems in which mathematical algorithms – calibrated on historical data – can take investment decisions.

Described changes influence the character of listing and therefore searching for correlation between patterns of investors' behaviours 15 years ago and currently is unjustified. For that reason, the paper uses tick data of five full years (2012-2016) of Ducascopy broker. The constructed binary strings of that period include, depending on the chosen discretisation unit, a number from several to a several dozens of binary values – such a number allows to run a reliable statistical analysis of a current course of currency market.

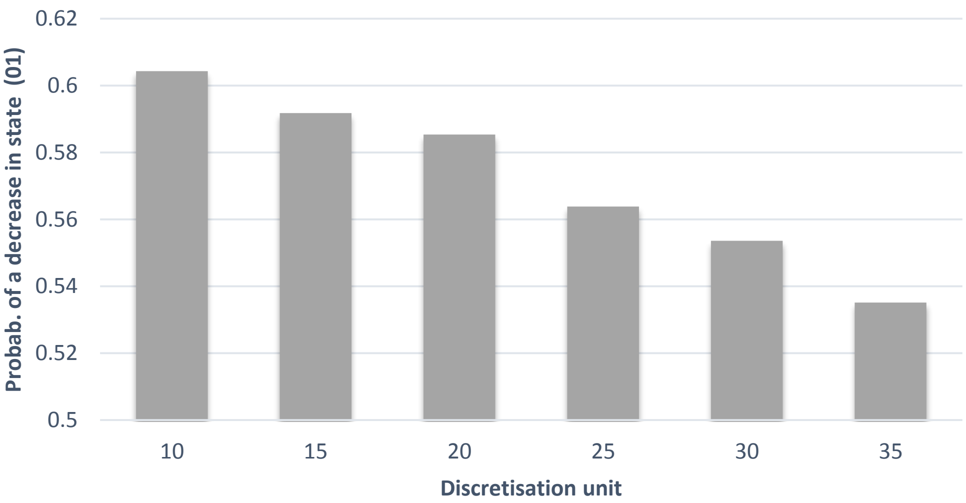
3. The choice of the optimum discretisation unit

A right choice of discretisation unit influences modelling results of the exchange rates noted in binary representation. Therefore, to use SMBR for exchange rates prediction (HFT system creation), the chosen value of discretisation unit should include such parameters as: values of transition probabilities, the accuracy of estimating those probabilities in time, the number of a state occurrence and some parameters offered by the broker, e.g. the value of spreads.

Prediction modelling bases on the adoption of the hypothesis on the existence of the dependency between the probability of the direction of changes in the exchange rates in relation to its preceding changes. If the exchange rate satisfies the effective market hypothesis (Fama, 1970) then building prediction systems is unjustified. To verify the hypothesis on the existence of the above-mentioned relation, four statistical tests commonly used, among other things, to test the generators of pseudo-random numbers, were used (Stasiak, 2016a). In the research the following tests were used: frequency test, runs test, non-overlapping template matching test and long run test. In case of all the chosen discretisation units, similar results were obtained. The first test confirmed a random character of changes – this result means a similar number of increases and decreases in exchange rate price (Chung, 2012; Rukhin et al., 2010). However, the other three tests indicate the existence of appropriate relations, i.e. a more frequent occurrence of some sequences and series of given lengths (Godbole and Papastavridi, 1994; Menezes et al., 1996; Rukhin et al., 2010). The assumed level of significance equals 0.01. The obtained results justify the implementation of the binary representation for modelling the exchange rates.

Let us consider the relation between an adopted discretisation unit and the probability of the direction of changes in the currency exchange rate in SMBR ($m = 2$). Figure 3 presents the values of probability of decrease for the state (01) in SMBR model. Along with the increase of the discretisation unit value, the probability value of the estimation of future direction of exchange rates decreases. Similar tendencies can be observed for other states of SMBR ($m = 2$).

Fig. 3 The probability of decrease in case of state (01) in SMBR model ($m = 2$) depending on the discretisation unit



Source: Own elaboration

Considering two relations between a chosen discretisation unit and the probability of future direction of changes, also the number of registered occurrences of particular states must be taken into consideration. This number influences the accuracy of estimations (the larger the number of examined changes, the more accurate the results), as well as the possibility of a practical use of SMBR for building HFT systems – a bigger number of transactions generates a bigger profit. Figure 4 shows the number of registered states (01) in SMBR model in the analysed period.

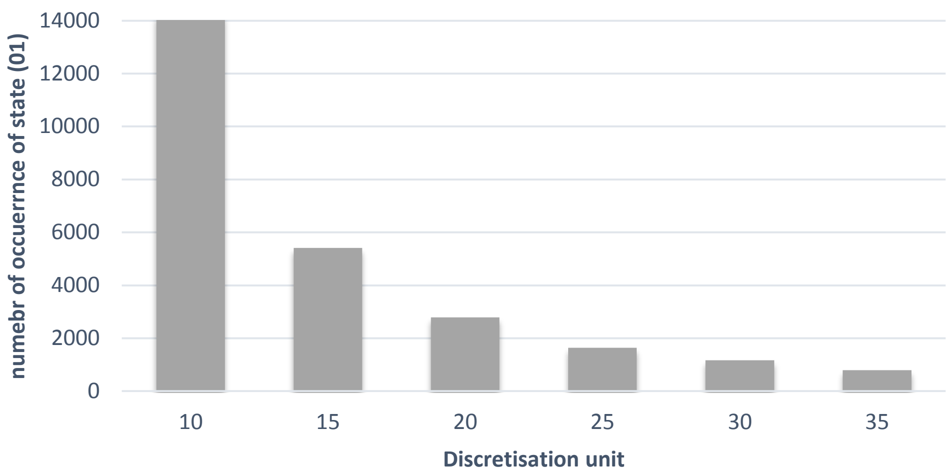
Judging by the research presented in figures 3 and 4, a following conclusion can be formulated: the decrease of discretisation unit is accompanied by an increase of probability value of a future change and the number of registered states. Similar relations were obtained for other states. Therefore, basing on conducted research, the choice of 10 pips discretisation unit would seem justified. However, the quality and the bankruptcy probability of HFT system depend not only on the value of probability estimation of direction of the future change but most of all on the accuracy of that estimation in time.

Many techniques of technical analysis, e.g. those being based on the average, are characterised by a high level of change probability of exchange rates in times of strong trends, however in times of exchange rates consolidation the probability of future direction changes of exchange rates, drastically drops which translates into a number of loss transactions and, consequently, into a high value of the parameter of the capital max drawdown (*MDD*) (Aldridge, 2009). This parameter defines the biggest registered drop of investor's balance and can be expressed as:

$$MDD(T) = \max\{\max\{X(s) - X(t): s \in (0, t)\}: t \in (0, T)\}, \tag{1}$$

where $X(t)$ is the value of the investor's account balance in moment t, whereas T defines the time of operating the HFT system. Let us consider two different algorithms generating transactional signals of TP and SL parameters, which are equally remote from the opening price by 20 pips. We assume that spread equals 2 pips. Both algorithms are characterised by 63% probability of future direction change (in this example both algorithms – 1 and 2 – generated 63 signals resulting in a profit and 37 signals resulting in a loss). Figure 5 presents fluctuations of investor's balance for two different investing algorithms.

Fig. 4 The number of occurrence of state 01 in SMBR model (m = 2) depending on the discretisation unit



Source: Own elaboration

In both cases the initial balance of an investor is 400$ which means that after 100 transactions the balance almost doubled (to more than 700$). However, one must notice that after 35 transaction the balance of an investor investing 400$ on the basis of algorithm 1 was zeroed which means that investor would lose its capital. In case of implementing algorithm 2, after a hundred of transaction, the investor has doubled its capital.

To estimate the accuracy of probability of a future direction change of exchange rates in time, the analysis of confidence interval for average values of transition probability in SMBR model (m = 2) was carried out. For each discretisation unit the number of registers states was divided into 10 equal series. In each series the probability of a future direction changes of exchange rates and then, basing on T-student distribution, a 93% confidence interval was established. Table 1 presents the results for state (01), similar results were obtained for other states. The results show that the most accurate estimation of the probability of a future direction changes of exchange rates was reached for the discretisation unit of 20 pips. For a discretisation unit of 10 pips, despite the biggest number of registered states, confidence interval is twice as big. Such a result means that despite a higher value of the estimation of probability of a future direction changes of exchange rates, a potential HFT system based on 10-pips discretisation unit will be characterised by bigger fluctuations of investor's balance and, consequently, a higher risk taken by an investor.

Tab. 1 The relation between confidence interval and discretisation unit for the state (01) in SMBR(m = 2) model

	State (01)					
Discretisation unit	10	15	20	25	30	35
Confidence interval	0.07124	0.0300616	0.0270616	0.03263	0.031489	0.042101

Source: Own elaboration

When choosing the appropriate discretisation unit for building HFT system, based on SMBR model, one must also take into consideration the influence of a spread value on the investor's balance. For the considered currency pair of AUD/NZD brokers offer low levels of spreads (for instance, ICMarket broker offers an average spread of 1.4 pips).

In HFT system based on SMBR model the distance between parameters TP and SL, and the opening price equals a discretisation unit. To establish a nominal value of a potential profit or loss, the value of the spread must be accounted for. A potential profit or loss can be denoted as follows:

$$Profit = (DU - spread) * Lot, \tag{2}$$

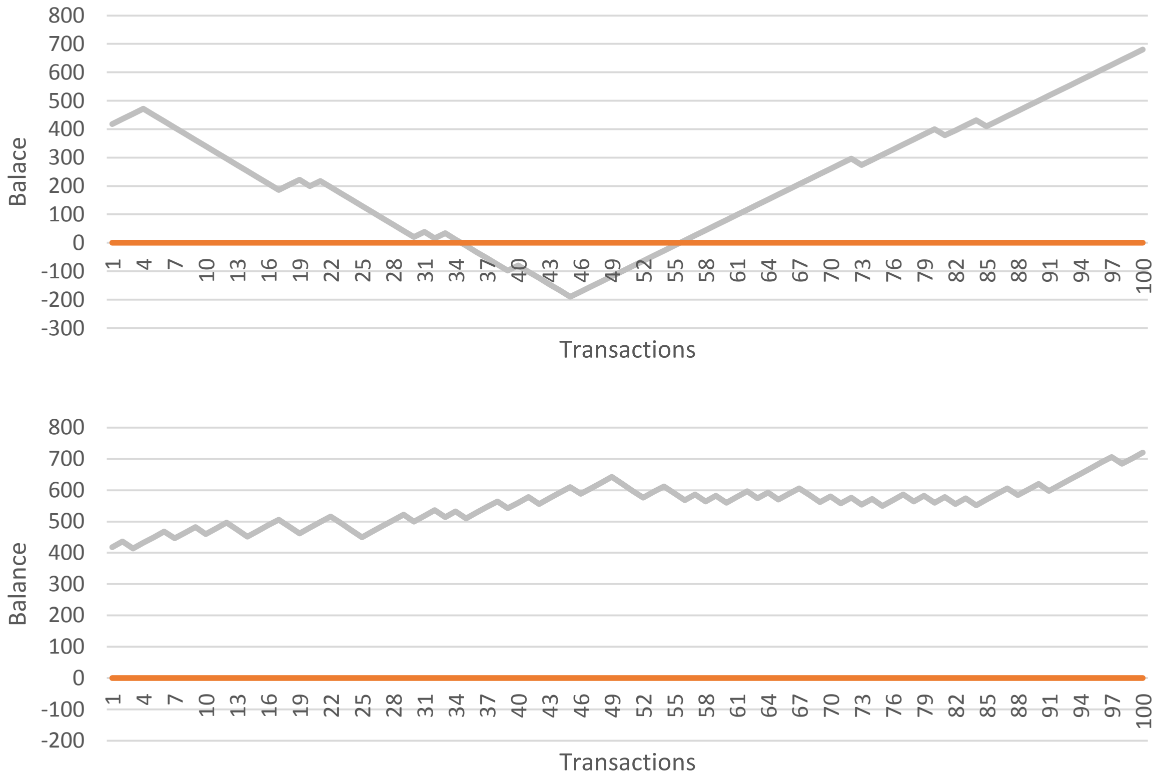
$$Loss = (DU + spread) * Lot, \tag{3}$$

where *Lot* is a unit which describes a magnitude of a transaction (it equals 100000 units of a basic currency). Assuming an equal value of all positions, this parameter only scales the value of a position and does not matter in the context of elaborations presented in the paper. The *DU* parameter is the discretisation unit.
Basing on equations (2) and (3), after elementary transformations, a threshold of the change probability estimation P_g, can be calculated above which HFT system – based on SMBR model – will generate the profit:

$$P_g = \frac{(Du+spread)}{2\,DU}, \tag{4}$$

Equation (4) enables – when the spread, discretisation unit and the probability of change direction is known – to define whether HFT system will, in long-term, generate profits or losses. The increase of the difference between the threshold (equation (4)) and the probability of future change direction will lead to a greater profit generated by HFT system.

Fig 5. The examples of balance fluctuations for various algorithms of signal generation



Source: Own elaboration

To choose an appropriate discretisation unit, one must take into consideration the value and accuracy of the probability of the future change direction, the number of potential transactions and the influence of offered spreads. The analysis of historical 5-year periods indicates that the optimum value, in terms of obtained values of the probability of future change direction and a number of signals is 10 pips, the smallest discretisation unit. However, significant fluctuations of the estimation of the probability of future change direction in time (almost twice as big level of confidence than for 20 pips discretisation unit) and the influence of the spread (the values of *P* of 59%) indicates no justification for using 10 pips discretisation unit to build HFT systems. Taking into consideration the accuracy of the forecast (confidence interval) and the number of appropriate states occurrence it seems justified to choose a discretisation unit of 15 or 20 pips. A much smaller number of signals and a lower value of the estimation of probability of future change direction also excludes the discretisation unit bigger than 20 pips. A larger number of signals generated for a discretisation unit of 15 pips, compared to 20 pips discretisation unit, is balanced by a larger spread. The profit generated by HFT systems, based on SMBR model using 15 and 20 pips discretisation unit will be similar. Therefore, using such values of discretisation unit in HFT systems seems to be an optimum solution.

4. Conclusions

The exchange rate can be presented in a form of the binary representation which is an alternative solution to less accurate candlestick charts. Binary representation of exchange rates can be used to build effective HFT systems. In those systems the probability of a following change of exchange rates is interpreted as the possibility of a profit or loss. To model the exchange rate, basing on binary representation, we can use a state model for binary representation (SMBR).

The choice of the optimum discretisation unit depends on the value and accuracy of the estimation of the probability of future change direction, the number of potential transactions and the value of available spreads. The paper, in detail describes particular factors and runs an exemplary analysis which justifies the choice of individual discretisation unit for the currency pair of AUD/NZD. The above-presented analysis is of a universal character and can be used to choose appropriate discretisation units for other currency pairs.

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