# FOREX meet A.I.⋆

Marco Fisichella[1,∗], Filippo Garolla[b]

[a]*L3S Research Center of Leibniz University of Hannover, Germany*
[b]*Austria*

**Abstract**

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*Keywords:* `elsarticle.cls`, LaTeX, Elsevier, template
*2010 MSC:* 00-01, 99-00

## 1. Introduction

**TODO:** dire che la nostra ricerca si basa sul fatto che oggi il X% dei tarding e' fatto da computer.

People are involved more and more in trading of currencies these days. Amongst those markets, of the biggest buying and selling platforms are cryptocurrency trading and the Forex marketplace. Although cryptocurrency promises better returns than foreign exchange, Forex gives solid, especially secured, and relatively regulated trading in comparison to cryptocurrency trading. As a result, in latest years, the foreign exchange (Forex) market has attracted pretty a lot of interest from researchers all over the world. Different kinds of studies have been performed to accomplish the task of predicting future Forex currency prices accurately.

Researchers have been involved primarily in neural networks models, pattern-based approaches, and optimization techniques. The emergence of artificial neural networks performed a massive function in foreign exchange rate prediction. During our evalutaion of related works, we discovered that many deep learning algorithms, such as gated recurrent unit (GRU) and long short term memory (LSTM), have been explored and exhibit massive potential in time sequence prediction.

The foreign exchange market, is the world's largest foreign money trade market with over 5.1 trillion of trade exchange per day. It is recognized to be very complicated and volatile. Currency trading occurs 24 h a day, however the buying and selling time is divided into 4 fundamental time zones. Each of these zones has its specific opening hours and closing hours. Forex is divided into three specific categories: majors, cross-rates, and exotics. Majors are the most traded currencies which are priced in opposition to the USD and occupy the majority of the Forex market. Our work is primarily based on Majors.

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∗Corresponding author
*Email address:* `mfisichella@L3S.de` (Marco Fisichella)

Each Forex pair has its opening price, highest price, lowest price, and closing price based on the trading session. For security reasons, it is now not possible for one person to at once go to, register with, and purchase from the Forex market, but each individual needs to use third party like brokers, who are humans or corporations that have admission to the Forex market and are capable to buy or sell currencies. In the Forex market, solely two alternatives are available, either buying currencies or selling if they have brought any currencies previously.

Recent years have viewed a lot of researches in the Forex market foreign money rate prediction. Predicting the Forex market has been a key goal of investigators over the preceding couple of decades. There are two methods to forecast the market: undamental research and technical research. Fundamental research considers many factors, such as the financial system and political state of a country, the popularity of a company, all inner and exterior buying and selling news, etc. Technical research concentrates predicting the Forex market based totally on historic data, in particular, the highest price, lowest price, opening price, and closing price of a currency and the volume traded on a particular day.

**TODO:** The remainder of the paper is arranged as follows.


## 2. Related Works

Numerous hybrid techniques have been examined in preceding years. Based totally at the papers we reviewed, according to the principle set of rules the studies prioritised, the papers can be cut up into going in conjunction with the following categories: regression strategies, optimization strategies, neural networks, and others. Those classes had been made in keeping with the popularity of the principle method of the forecasting system in the past years.

**TO DO:** In conclusion, these techniques are not appropriate for all currency pairs and may provide better effects for only a few randomly selected ones, as we can see inside the proposed papers.

Some pattern-based approaches are contradictory to each other.

### 2.1. Regression Methods

Raimund et al. [1] proposed a hybrid model for foreign exchange prediction that makes use of wavelet models along with support vector regression (SVR). Before everything, they used a discrete wavelet transform (DWT) technique to interpret facts from their Forex dataset. Then the data were used as the input of support vector regression (SVR) for predicting the foreign exchange prices. They analysed the overall performance of their system with ARIMA and ARFIMA models. The effects confirmed that their system performs higher than ARIMA and ARFIMA models.

Taveeapiradeecharoen et al. [2] proposed a version for time series inspection and prediction; this is based on compressed vector autoregression. At the start, they used random compression method to decrease a big wide variety of foreign exchange data into a smaller form. After that, they used the Bayesian model averaging (BMA) approach to establish the load of each random compressed datum to attain the intersecting parameters. Their approach can provide out of sample forecasting till fourteen days previous to the real time. They concluded that their system was not suitable to predict all of the 30 Forex currencies. Their proposed study outperformed the existing benchmark of Bayesian autoregression for specific 6 foreign money pairs.

A huge range of forecasting models have been proposed via the authors of the paper [3], by applying linear kernel SVR to historical data for EUR/USD, GBP/USD, and USD/JPY currency pairs received from high-frequency trading. Previous successive timeframes are used as features to predict the movement of rates in future/next time frame. Upon building models, they found a easy rule that supplied high-quality results.

After reviewing recent papers, it's evident that support vector regression turned into the most used approach included in our reviewed papers. Compressed vector autoregression, the CRT regression tree, and partial least squares regression had been additionally utilized by researchers. However, there are different algorithms which include lasso regression, logistic regression, and multivariate regression which have been abandoned in later years. The reviewed literature shows that the system primarily based on a regression model performed higher than ARIMA and ARFIMA models [1], and the model performance may additionally growth [4] when a regression model is combined with other techniques. However, when operating with a huge number of foreign money pairs, it is able to become hard with regression techniques, as most of the currency pairs return a higher MSE [2].

## 2.2. Optimization Techniques

Chandrinos et al. [5] proposed a technical system for Forex that was stimulated by using the Donchian channel method. the primary reason in their method become to create profitable portfolios for Forex buying and selling strategy. They first constructed the modified Renko bars (MRBs) via combining their trading guidelines. Their changed MRBs proved to be more correctly responsive than the normal candlesticks used in Forex. They created an optimization level used by eight currency pairs. To acquire their optimization stage, they used three search-derivative-free global optimization strategies. These algorithms were the swarm optimization algorithm, also referred to as dividing a hyperrectangle (DIRECT), along side multilevel coordinate search (MCS), and pity beetle (PBA). They examined their optimization method and primarily based on the total return they built two kinds of portfolios: an equally weighted portfolio and a Kelly criterion-based portfolio. They evaluated the performance in their approach primarily based at the geometric return, arithmetic mean, and Sharpe ratio. They found out that the proposed version isn't always suitable for three currency pairs, whilst for the others they attain from 29% until over 200% general return.

Pradeepkumar et al. [6] advised a model for foreign exchange prediction that became primarily based on a quantile regression neural network (QRNN) and particle swarm optimization. They used PSO to train the QRNN and named the version PSO-QRNN. They used 8 pairs currencies. They used seven unique algorithms for the overall performance evaluation of their model: group method of data handling (GMDH), multilayer perceptron (MLP), random forest (RF), a quantile regression neural network (QRNN), generalized autoregressive conditional heteroskedasticity (GARCH), quantile regression random forest (QRRF), and a general regression neural network (GRNN). Once they executed the Diebold–Mariano (DM) evaluation check on all of the test results, they found that their proposed PSO-QRNN version completed higher than all models on datasets. For the rest of the datasets, QRRF and QRNN carried out better than other approaches.

Das et a. [7] proposed a hybrid approach that turned into build the use of extreme learning machine's on-line sequential version and krill herd (KH). The krill herd (KH)

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was devoted to features reduction. They compared their proposed system with a recurrent backpropagation neural network (RBPNN) and extreme learning machine (ELM). They considered 3 elements: (i) without features reduction (ii) with statistical features reduction, and (iii) with optimized features reduction strategies. For optimized features reduction strategies, they used bacteria foraging optimization (BFO), krill herd, and particle swarm optimization techniques. They used four foreign currency pairs. For RMSE their approach performed first-class. However, in MAE overall performance, their proposed model didn't provide the satisfactory effects.

For foreign exchange buying and selling approach optimization, a genetic set of rules become employed by the authors of the paper [8] to evolve a various set of profitable buying and selling rules based totally on weighted moving average approach. They used a time series with 4147 observations inside a range of sixteen years from 2000 to 2015 and they used the close prices of four foreign money pairs. Developed approach yields acceptably high returns on out-of-sample data. The rules acquired using their genetic algorithm result in appreciably better returns than the ones produced by exhaustive search.

In conclusion, these techniques are not appropriate for all currency pairs and may provide better effects for only a few randomly selected ones, as we can see inside the proposed papers.

### 2.3. Neural Network

Ni et al. [9] proposed a model that predicts the time series of foreign exchange using the C-RNN approach. C-RNN uses a convolutional neural network and recurrent neural network. They used a statistics-driven method to study the changing characteristics of Forex. They used the past 10 years records until 2018 for nine currency pairs. 2000 datapoints were contained in their dataset. Using a convolutional neural network and long short-term memory, evaluating RMSE, they discovered that their proposed C-RNN version offers much less mistakes than LSTM and CNN.

Chandrinos et al. [5] proposed a model referred to as the artificial intelligence risk management system (AIRMS) this is based on machine studying. They advanced two risk management structures: One with a neural network (AIRMS-ANN) and the other with the decision tree approach (AIRMS-DT). They used five Forex currencies and the technical indicator and historical time-series data as the input to their proposed model. They divided the output signal into two categories: profitable and not profitable. When they categorized the output signal only as profitable, they were given an growth of 50% profit over the 2-category labelled version. As assessment metrics, they used the F1 measure for both models. Each AIRMS-ANN and AIRMS-DT carried out well on average and outperformed each other in some cases. Whilst evaluating the Kelly criterion portfolios, the decision tree once more beat the neural network with respect to total return.

Dash et al. [10] proposed a model that makes use of a higher order neural network for Forex prediction. They used a shuffled frog leaping approach with the Pi–sigma neural network for predicting dynamic and non-linear Forex prices. Three currencies had been used for imposing their model. The ISFL algorithm was used for estimating the hidden parameters and improving the prediction price. ISFL algorithm is a progressed model of the shuffled frog leaping algorithm (SFLA) wherein convergence the speed of the network is enhanced along side the predictive potential of the network. They compared

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the performance of their approach with a range of different ones. Their model furnished higher accuracy in conjunction with higher statistical performance.

Recent study conducted by Ahmed et al. [11] suggests that a significant enhancement inside the prediction of Forex prices may be executed through incorporating domain information in the system of training machine learning models. The proposed approach integrates the foreign exchange Loss feature (FLF) into a long short-time memory model called FLF-LSTM, that minimizes the difference between the actual and predictive average of foreign exchange candles. The usage of $10,078$ 4-hour candles of EURUSD pairs highlighted that, compared to the classic LSTM version, the proposed FLF-LSTM model shows a lower overall mean absolute error rate by $10.96\%$.

The neural network became pretty popular in recent years. Many algorithms, inclusive of the modular neural network and deep belief model are yet to be explored. The reviewed literature implies that neural network-primarily based models may be equipped with unique types of procedures, which proves the versatility of those models. but, in some systems, a big network length can also have an effect on the result.

### 2.4. Rest of the Methods

In this section, we present the rest of methods proposed in literature. Far from being an exhaustive collection of all approaches, we wanted to analyse the most recent works in this field and give the reader an overviews of the remaining methods found in literature.

The genetic algorithm and SVM hybrid version had been quite extensively used strategies. The best function of the SVM is that it could be used as a classifier [12] and a regressor for forecasting [13]. The literature advised that after a SVM is incorporated with the genetic algorithm the model can yield a greater return of investment [12]. Nevertheless, on occasion selecting the wrong kernel may offer a huge difference within the end result [13]. Moreover, some approaches rely on the choice of learning model, inputs, and selection mechanisms.

Another perspective is shown by researches exploiting the chaos theory. Studies prove that chaos's extensive applicability can be used in a broader way. Lee et al. [14] indicates that chaos theory can successfully be used as both an economic time series predictor and as a trading strategy optimizer. The issue is deciding on the input parameters. The methods are selected based totally on the dynamics underlying the selected data and what type of evaluation is meant for the system. That makes the system tremendously complex and not always accurate.

Pattern-based techniques have seen pretty a recognition. Recurrent reinforcement learning (RL), dynamic model averaging (DMA), dynamic conditional correlation (DCC), and so forth., were explored through the researchers. Pattern-based methods also proved their flexible adaptability. A few systems can alternate the statistics of the predictors by using the object properties [15] that can be carried out to layout a selection of time series structures. However, some pattern-based approaches are contradictory to each other, as some systems carry out nicely and offer excellent outcomes with a specific algorithm [16], at the same time as other systems perform just the opposite [17]. Additionally, some pattern-based models are only capable of predicting the changes over a short-time period and do no longer guarantee success for longer period of prediction time [18].

Finally, the rest of the strategies incorporate several kinds of methods which have been applied for the forecasting of the Forex marketplace. It became determined that

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Bayesian autoregressive trees (BART), random forest (RF), naive Bayes (NB), ARIMA, and many others have been implemented and explored. A number of these algorithms have been carried out individually, whereas a few have been carried out in a hybrid version. Natural language processing become not often explored, however techniques such as NLP based on sentiment analysis that relies upon on news headlines [19] can easily be misguided using wrong news. As a result, right security measures need to be carried out on these methods.

## 3. Preliminaries

### 3.1. Trading in Forex

In first instance, an order is a request to make a trade to open a position. A trade is made when the order is matched to a counterpart, i.e a buyer has found a seller, or vice versa. Once a trade is opened, it constitutes a position. A position is exposure to the market and will move the balance in the account up or down in line with market movements. Placing an order to close a position will result in a trade opposite to the direction initially took, e.g. if we initially bought, now we sell to close. When we open a buy position, we are *long*, while when we sell we are *short*.

To be able to start a exchange in Forex, one need to open a position. There are alternatives to open a position: both buying the base currency and selling the quote one (going long) or selling the base one and buying for the quote forex currency (going short). The base and quote currencies are the first and second currencies in a foreign money pair, respectively. For instance, GBP is the base and USD is the quote currencies in GBP/USD forex pair.

A trader can use leverage within the buying and selling. Leverage is the ratio which lets in to trade big amount with a small sum of money. As an instance, if one trades $ 1000 with a leverage 1 : 30 in GBP/USD, the amount of buying and selling transaction will be $ 30,000 instead of $ 1000. The profit or loss of a buying and selling transaction is calculated with the aid of subtracting the final value from the initial price of the foreign money pair. Assume the trader goes long $ 30,000 in GBP/USD with a buying price of 1.4060 and closes his position with a selling price of 1.4090. The difference is 0.0030 equals to 20 pips. Due to the fact the initial position is long and price went up, the transaction is profitable and the earnings is $30,000 * 0.0030 = \$90$. Consequently the trader wants the price of the forex pair to growth whilst he/she is long and decrease when he/she is short to be able to get profit.

### 3.2. Trading System: Meta Trader 5

Since its introduction in 2005, MetaTrader 4 has become the most popular trading platform in the Forex world. It is supported by dozens of brokers worldwide, and offers traders the ability to program custom trading systems and indicators in the MQL language. The wide adoption of MetaTrader Forex brokers has created a large worldwide community of users.

In 2010 MetaQuotes launched the public beta of MetaTrader 5. The new platform introduces support for additional financial instruments, including futures and stocks. A one-click trading interface allows you to open orders quickly. Charts now support custom

periods. For discretionary traders, MetaTrader 5 [1] has a built-in news calendar and a wide variety of chart objects, including Elliott, Gann and Fibonacci tools.

But the biggest change in MetaTrader 5 has been the new MQL5 programming language. The latest version of MQL has been rebuilt from the ground up as a modern object-oriented programming language. Many new features have been added, including new data types, events, chart operations and more. The redesign of MQL5 also means that it is a much different language than MQL4. MQL5 is much more powerful and efficient than its predecessor [20].

We used MQL5 to implement an *expert advisor* that is an automated trading program that can open, modify and close orders. The end goal of our research is to provide to the community the implemented expert advisor [2], which was developed using the MetaEditor as IDE (Integrated Development Environment) for MQL5, included in Metatrader 5, and extending the shared code written by Young [3] .

*3.3. Technical indicators*

Technical analysis is the observation of past market motion with the scope to forecast future prices and to deal with the effect of the market movement. Two are the main approaches considered in this analysis. Based on charts, the analysis tends to detect patterns in price charts. There are 4 main types of charts used by traders: Bar chart, line chart, candlestick chart and point and figure chart. We use Candlestick chart.

The candlestick is a type of graphical representation of the prices in the time, similar to the Bar chart but is of easier reading.
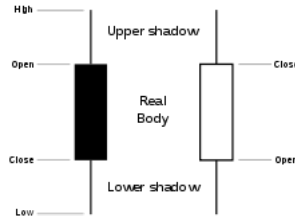


Figure 1: Candlesticks.

In Fig. 1 are represented some characteristics of the candlestick: first of all we notice the colour of the said Real Body, that it identifies the amplitude of the price between the opening and the closing, then two connected appendices called shadows and therefore upper shadow for that advanced and lower shadow for that inferior.

A candlestick with a closing price higher than the opening one is called *Bullish* and it has *white* colour, while *black* for those ones with a closing price lower than the opening one, called *Bearish*.

The Candlestick charts form in the time pattern that are identified according to the amplitude of the body, according to the conformation and the succession of candles or groups of candles [21].

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[1]https://www.metatrader5.com/en/trading-platform
[2]https://git.l3s.uni-hannover.de/mfisichella/forex
[3]http://www.expertadvisorbook.com/MQL5BookSourceCode.zip

It is well to notice that when the lower shadow is particularly long, the probabilities of reversal increase, the candle assumes one strong connotation of reversal. In fact, more long they are the shadows, greater it is the sense of instability of the market and more probable will be the signal of reversal.

In our trading system, 20 technical indicators are used as the basis of trading rules. These technical indicators are: Adaptive Moving Average, Average Directional Moving Index, Donchian channel, Stoller Bands, Bollinger Bands, Double Exponential Moving Average, Envelope Moving Avarage, Parabolic SAR, Fractal Adaptive Moving Avarage, Standard Deviation, Triple Exponential Moving Average, Avarage True Range, Bears Power, Bulls Power, MACD (Moving Average Convergence Divergence), Stochastic oscillator, William' Percentage Range, Momentum, RSI (Relative Strength Index), and Heiken Ashi Candles.

*3.4. Trading Rules*

From each indicator listed in Section 3.3, we derive a trading rule. In specific, a trading rule is actually a rule that generates short and long signals. A signal is an indication to open a position on the market. In its simplest form, a trading rule may be such as comparing the value of an indicator against a threshold, that can be fixed or dynamically attached to a time series.
As an example, the Slow Stochastic may generates a short signal when the line %K, inside the area of iper-bought, crosses from the high towards the bottom the line %D; while the Slow Stochastic may give a long signal when the line %K, inside the area of iper-sold, crosses from the bottom towards the high the line %D.

Finally, trading rule may be more complex such as rules computed with dynamic channels, as described in Section 3.4.1.

*3.4.1. Trading Rules with Dynamic Channels*

Many operating strategies built for short-term trading use signals provided by what are known in technical jargon as *dynamic channels.* In some cases the strategies are of type trend following, that is they aim to follow the main trend present on the market, in other cases instead they are of type reversal in how much they try to take advantage of a possible reversal of trend. The principle of base of these operating techniques is based on the individualization of some bands of oscillation (envelopes) that:

- Contain for the greater part of the time the movement of the prices.

- They concur to characterize the trend followed from the prices.

- They supply interesting reversal signals.

These channels are dynamic in how much, measuring (even if in various way) the present instability on the market, they are adapted to the movements (cyclical) carried out from the prices, that alternate in fact phases of consolidation (in which the instability is reduced) to directional/impulsive phases (in which the instability increases in meaningful way). The technique of the bands requires the identification of:

- A central reference average, which serves to identify and exploit the primary trend present in the market;

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- A lower band and an upper band, which constitute respectively a support and a resistance of dynamic type (as they move according to the volatility recorded on the market) and which contain the movement of prices.

When volatility is low the two bands narrow and approach prices (the channel width is reduced), when volatility is high the two bands widen and move away from prices (the channel width increases).

We begin therefore with the description of the more used dynamic channels, beginning from the Channel of Donchian and the Bands of Stoller.

### Donchian channel.

One of the first operational techniques based on the use of channels was invented by Richard Donchian who built a trend following system based on the identification of the highs and lows of the last 20 days (the original system was based on the *Donchian 4-week rule*). With this technique:

- Long positions were opened when prices exceeded the highest high of the last 20 days.

- One would open short positions when they fall below the lowest low of the last 20 days.

With this technique one goes in search of the classic breakout signals that can initiate a directional movement. Draft however of a system that has been applied with success during the years ′80 on the market of the commodities (where the tendencies were stable and consisting) but that in the course of the time has diminished its efficiency. For this reason it has been gone to the search of techniques in a position to exploiting also the frequent and unexpected reversals of tendency that are verified when the prices catch up important zones of resistance and/or support.

### Stoller Bands.

An experienced commodities trader, Manning Stoller, has constructed an operating technique (Stoller Average Range Channels, STARC) which uses the concept of the Average True Range (ATR). This differs from the simple daily range (the difference between the high and the low price) in that it also takes into account whether there is a gap-up or gap-down. The ATR is the greater of these three differences:

- Today's maximum price minus today's minimum price.

- Today's maximum price minus yesterday's closing price.

- Yesterday's closing price minus today's low price.

To calculate the Stoller Bands, a 6-period moving average is calculated, to which the 15-period moving average of the Average True Range multiplied by two is added (to obtain the upper band) and subtracted (to obtain the lower band). There are therefore three reference lines:

- The Upper Band equals to the 6-period moving average plus $(ATR * 2)$.

- The Central Average equals to the 6-period moving average.

- The Lower Band equals to the 6-period moving average minus $(ATR * 2)$.

The difference from the technique proposed from Donchian (of trend following type), the Stoller Bands come used in order to obtain of the signals of reversal. In particular:

- Short signals are obtained when prices go beyond the upper band and draw a reversal short bar (for example a shooting).

- Long signals are obtained when the prices come down under the inferior band and draw a bar of reversal long (as an example a hammer).

### Bollinger Bands.

Bollinger Bands are composed of three lines: a central moving average and two bands, one upper and one lower, which automatically widen and narrow according to the volatility expressed by the market. The calculation of Bollinger Bands, according to the original formula of its creator, is simple:

- The value of the upper band is obtained by adding to the central moving average (e.g. at 20 periods) the value of the standard deviation multiplied by two.

- The lower band is obtained by subtracting the standard deviation multiplied by two from the moving average (e.g. at 20 periods).

In this way, when the market is moving sideways, volatility is reduced and the two bands compress around prices. When the market is in a directional phase (either positive or negative), volatility increases and the two bands move away from the prices.

The strategies that can be constructed with the Bollinger Bands are substantially two:

*1. The volatility breakout.* When the bands are compressed around the prices, it means that on the market a marked contraction of the volatility has been verified, situation that can anticipate the beginning of an impulsive movement that often is born with a bar of breakout bullish or bearish. In this case it can be constructed a strategy of trend-following type, time to exploit the trend bullish or bearish that is established thanks to the breakout. For example:

- A long position can be opened when prices, following a breakout, accelerate to the upside and push beyond the upper band. The signal must be confirmed by both a close of the candle which is above the upper band and the next candle, which must not be bearish.

- A short position can be opened when prices, following the breakout, fall rapidly and fall below the lower band. The signal is confirmed both by a close of the candle which is below the lower band and by the next candle which must not be bullish.

This is an interesting strategy from a theoretical point of view, but it can result in a late entry into the market, with prices having already made a significant movement.[4]

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[4]In order to use signals of breakout it is preferable to use the Channel of Keltner, much more rapid in signalling the beginning of a directional trend.

*2. The signals of reversal.* The second technique is of reversal and is that one that is preferred, in how much it exploits the exhaustion of a movement to the rise or the end of a trend negative, and is based on the individualisation of a configuration of reversal, that it is verified when the prices are carried to contact of one of the two bands:

- A bearish signal occurs when the market rips to the upside, crosses the upper band (the upper shadow of the first candle is above the upper band), but then prices undergo a correction and return just below the band itself and the next session draws a bear candle.

- A bullish signal is had when the market accuses one brusca decrease, comes down under the inferior band (the first candle has one lower shadow under the inferior band), but then the prices bounce and return endured over the same band and draw one second candle bull.
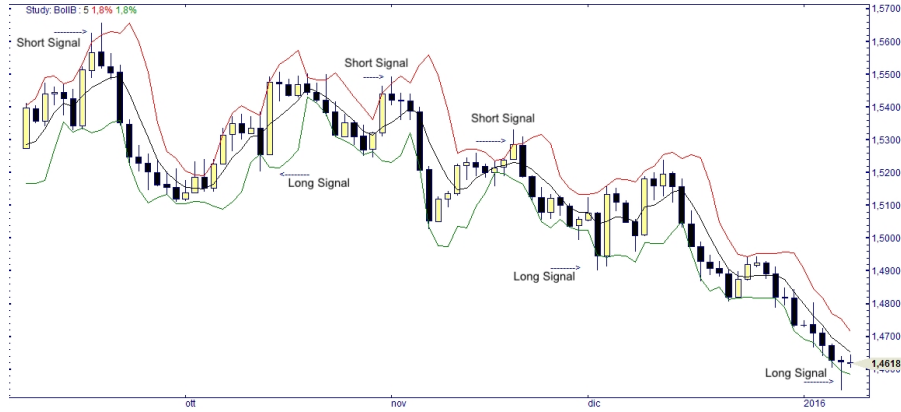


Figure 2: USD/GBP Chart: signal generated by the *signals of reversal* technique on the Bollinger Bands.

As an example, we report in Fig. 2 the signals short and long generated by this technique on USD/GBP chart [5] .

## 4. The Trading System

In this section, we present our trading system which uses the trading simulation layer and GA to select and combine trading rules coming both from technical indicators, as depicted in the previous section, and from our AI layer, described in Section 4.1.2, to generate buy/sell signals. The trading system uses time series price data of 6 currency pairs: 4 major pairs like GBP/USD, EUR/USD, USD/CHF and USD/JPY, and 2 minor pairs like EUR/GBP and GBP/JPY.

The idea to combine trading rules it is borrowed by the real world of trading, where traders and analysts, before opening positions on the market, try to confirm their decision using different approaches and indicators.

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[5]Source: Trading, G. Probo, Hoepli

Two phases constitute our proposed trading system: in the first phase, each trading rule, both the AI-based rule and the trading rules from technical indicators, are tested for selection and in the second phase, profitable rules among the qualified rules are selected and combined. Training data is used in the learning step of the trading system.

An overview of the two phases of the proposed framework is illustrated in Fig. 3. In the following sub-sections, the phases of the system are explained in detail.
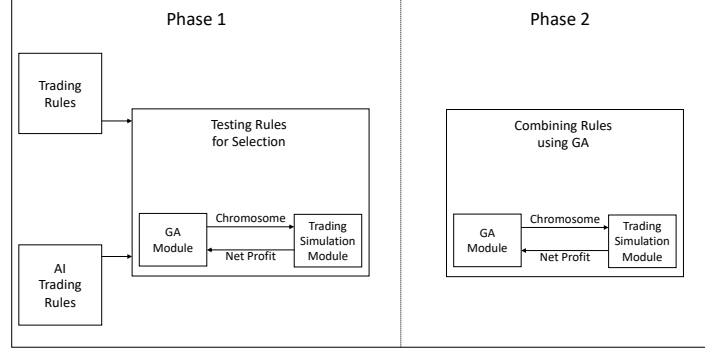


Figure 3: The framework of our trading system.

### 4.1. Phase 1: each trading rule is tested for selection

The goal of this first phase is the selection of trading rules, both the AI-based rule and the trading rules from technical indicators. Three layers are employed in such a phase: AI (Section 4.1.2), GA (Section 4.1.3) and the Trading Simulation (Section 4.1.1) layers.

As depicted on the left part of Fig. 3, each trading rules from technical indicators, as discussed previously, and the AI-based rule are given as input to the GA layer which randomly generates chromosomes representing their genes with several parameter combinations both directly related to the specific trading rule (e.g. period $D$ for the Slow Stochastic Oscillator rule) and related to the trade (e.g. the money management risk in percentage, $risk\%$, explained hereafter). Then, all of these candidate rules with several parameter combos are simulated over the historical training data using the Trading Simulation layer which gives as output the Net Profit provided as the fitness value to the GA layer. Following, the best performing chromosome for each rule in term of net profit is selected. The rules whose best chromosome does not have a positive net profit are directly eliminated and do not pass to the second phase.

### 4.1.1. Trading Simulation Layer

This layer is used to simulate any buying and selling rule on the given time series data with respect to specific currency pairs in order to generate buy/sell/StopLoss/TakeProfit signals (hereafter explained) and calculate net profit as well as different statistics (number trades/deals, total net profit, number of ticks, balance drawdown absolute/max/relative, consecutive wins/profit, consecutive losses, and many others) at the end of the simulation. Our trading simulation system adopts a realistic approach to compute the net

profit: we use a demo account with a trading broker [6] simulating the placement of buy/sell positions. Our choice to go through a demo trading account is fundamental for realistically computing the gain and loss of our proposed approach. Finally, the net profit of the simulated trading rule is used as fitness value for the GA layer.

The simulation of the placement of a buy order is given in Algorithm 1. Similarly is done the placement of a sell order.

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[6]https://www.icmarkets.com/en/open-trading-account/demo/

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**Algorithm 1:** Opening a BUY position

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**Input:**

$signal$: A trading signal: trading rule BUY signal to open BUY position;

$marketMovingHoriz$: Definition of Market moving horizontally;

$symbol$: The selected currency pair;

$stopLoss$: Initial fixed Stop-Loss in points;

$takeProfitXSL$: Multiplier factor of Take-Profit with respect to Stop-Loss;

$sellPosCount$: The count of open SELL positions;

$fixedVolume$: Volume in lots;

$riskPercent$: Maximum risk per trade with respect to the current balance;

**Output:** A list of opened positions

**while** $OnTick()$ **do**

  $newBar=$ CheckNewBar();

  **if** $(newBar == true)$ **then**

    /* Open BUY position and close all SELL positions        */

    **if** $(signal == BUY)$ **then**

      /* Close open SELL positions                 */

      **if** $(sellPosCount > 0)$ **then**

        CloseAllSellPosition();

      /* Do not open another BUY if there is a current BUY position

         opened with a price in a close range             */

      **if** $(currentBar.Close > (lastPriceBuyOpenPosition +$ $(marketMovingHoriz/2))\|currentBar.Close <$ $(lastPriceBuyOpenPosition - (marketMovingHoriz/2))$ **then**

        /* Compute StopLoss, expressed in points        */

        $dynamicStopLoss = $ DynamicStopLoss();

        $stopLossDistance = $ MathMax$(dynamicStopLoss, stopLoss)$;

        /* UseMoneyManagement                     */

        $tradeSize=$MoneyManagement$(symbol, fixedVolume, riskPercent, stopLossDistance)$;

        /* takeProfit is X times stopLoss           */

        $buyProfit = $ BuyTakeProfit$(symbol, takeProfitXSL, currentBar.Price)$;

        /* Buy                                 */

        $glBuyPlaced=$TradeBuy$(tradeSize, stopLossDistance, buyProfit, symbol)$;

---

We first check if a new bar occurred. This is important to adhere to the respective period chosen, e.g. 1-minute, 5-minute, 15 minutes, an hourly, daily and weekly bar chart and so on. For our experimentation we chose 4-hours (4H). Secondly, we check if a signal $BUY$ has being triggered. If so, we verify if sell positions are still open and close them. Then, we check if there is another buy position opened previously with a price in a close range of the current one. If so, we do not open a new open position.

At this point, we compute the trade size using the money management function, the stop

loss and the take profit. Finally, we open the buy position. In the following sub sections, the details of the latter computations.

**Money Management for computing the trade size.**
Money Management is a procedure to best set position size with respect to risk. Most traders use the same fixed trade volume for every trade. This can result in trades that are too large or too small for the amount of money that is being risked.

To calculate an optimal trade size, we use the distance of the stop loss price from the trade entry price as well as a percentage of the current balance to determine the maximum risk per trade. A good guideline is to limit your risk per trade to 2-4% of your current balance. This value was computed by our GA layer (more details in Section 4.1.3), where the risk-value is represented as a gene (i.e. $risk\%$) of a chromosome. If for some reason we cannot calculate a trade volume (i.e. stop loss or percentage has not been specified), we will fall back to a specified fixed trade volume.

Let's show the Algorithm 2 that explains the $MoneyManagement()$ method of Algorithm 1.

---

**Algorithm 2:** Money Management method

---

**Input:**
$MAXPERCENT$: Is a constant specifying the max risk and set to 10%
$symbol$: The selected currency pair;
$fixedVolume$: Default trade volume in lots;
$riskPercent$: Maximum risk per trade with respect to the current balance;
$stopLossDistance$: Stop Loss distance in points;
**Output:** $tradeSize$: Calculated trade volume
**if** $(riskPercent > 0)$ & $(stopLossDistance > 0)$ **then**
 **if** $(riskPercent > MAXPERCENT)$ **then**
  riskPercent = MAXPERCENT;
 margin = AccountInfoDouble($accountBalance$) * ($riskPercent$/100);
 tickSize = SymbolInfoDouble($symbol$);
 tradeSize = ($margin/stopLossDistance$) / $tickSize$;
 tradeSize = VerifyVolume($symbol, tradeSize$);
 return($tradeSize$);
**else**
 tradeSize = $fixedVolume$;
 tradeSize = VerifyVolume($symbol, tradeSize$);
 return($tradeSize$);

---

The $tradeSize$ will hold our calculated trade volume. First we check if $riskPercent$ and $stopLossDistance$ are both greater than zero. If not, then we cannot calculate the trade volume, and we will fall back on the default trade volume specified by $fixedVolume$. Otherwise, if both $riskPercent$ and $stopLossDistance$ are valid, then we will proceed with calculating the trade volume.

Next, we calculate the amount of margin to risk, retrieving the account balance using the AccountInfoDouble() function. Then we retrieve the tick size and store that in

*tickSize*. The tick size is the amount of profit or loss represented by a single point move.

To calculate our trade volume, we divide the margin to risk (*margin*) by the stop loss in points (*stopLossDistance*) and divide the result by *tickSize*. Then we pass our calculated trade volume to VerifyVolume() function. The latter verification is done since most Forex brokers allow trade sizes as small as 0.01 lots, but some brokers have a higher minimum trade size or do not use micro lots.

Let's clarify this with an example. We want to place an order risking no more than 2% of our account balance of $ 5000. The initial stop loss will be placed 500 points away from the order opening price. The symbol is EUR/USD and we are using mini lots of 0.1, so the tick size will be $1 per point. 2% of $5000 is $100, so this value will be saved in the *margin* variable. The value of the *tickSize* variable will be $1. $100 divided by 500 points is 0.2. Every point of movement will equakl approximately $0.20 of profit or loss. 0.2 divided by $1 equals 0.2, so our trade value will be 0.2 lots. If this trade of 0.2 lots hits its initial stop loss 500 points away, the loss will be approximately $100. If the stop loss distance is 200 points aways, the trade valume will be 0.5 lots, but the maximum loss is still $100.

### Stop Loss and Take Profit.

Many trading strategies place the stop loss and take profit a fixed distance from the order opening price. The trader specifies the number of points for the stop loss and take profit that are then calculated to the order or position opening price. For a market order, the opening price is the current Bid or Ask price at the moment the order is filled.

**Stop Loss:** For a buy order, the stop loss is calculated by subtracting the stop loss value in points from the opening price. For a sell order, the stop loss is calculated by adding the stop loss value in points to the opening price. First, the symbol's point value is multiplied by the stop loss value. For example, a Forex symbol with five digits after the decimal points will have a point value of 0.00001. If we have specified a stop loss of 500 pints, we multiply 500 by 0.00001 to get a value of 0.005. This value is then added or subtracted from the opening price to find the stop loss price.

**Take Profit:** As a stop loss price is computed, as well the take profit price is calculated, only in reverse. The take profit price for a buy order is placed above the opening price, while the take profit price for a sell order is placed below the opening price.

One of the most common error made by traders is invalid stop prices. A stop loss or take profit must be a minimum distance away from the current Bid and Ask prices. The minimum distance is called *stop level* and it is retrieved from the broker server. Before we attempt to place an order with our new calculated stop loss or take profit price, we need to verify the price to make sure it is not inside the stop level.

So far we introduced an initial fixed stop loss in points, but there are other ways of determining a stop loss price, such as using an indicator value or a technical support/resistance level. The DynamiyStopLoss() function in Algorithm 1 retrieves the lowest lowest Low (since we are opening a buy position, otherwise it would have been the highest High) of the last 5 bars and assign the result to *dynymicStopLoss* variable. For sake of clarity, this value of checking the last 5 bars was computed by our GA layer, where the interval-value is represented as a gene (i.e. *intervalSL*) of a chromosome. The same was, we computed the gene *takeProfitXSL*, as the multiplier factor of take profit with respect to stop loss, in points, and found out the best value equal to 2.

We conclude this paragraph introducing the trailing stop. A trailing stop is a stop loss that moves as a position increases in profit. For a buy order, the trailing stop moves up in price as the position gains in profit, and for a sell order, the trailing stop moves down in price as the position gains in profit. A trailing stop typically follows the current price by a specified number of points, defined in our algorithm as *trailingStop* variable. For example, if a trailing stop is set to 500 points, then the stop loss begins moving once the current price is at least 500 points away from the stop loss price. We can delay a trailing stop by requiring a minimum level of profit be reached first, specified in our algorithm as *minProfit* variable. Both *trailingStop* and *minProfit* values are computed by our GA layer as values of genes of a chromosome; the best output was found with *trailingStop* equal to 450 points and *minProfit* equal to 700 points.

Until now, we presented a fixed trailing stop, but we trailed also dynamically following an indicator, such as the Parabolic Stop and reverse (PSAR) indicator. The PSAR was used to set as stop loss that progressively moves closer to the high or low of the current bar. When the PSAR value gets close, or the trend reverses, the PSAR will reverse direction. If the PSAR is below the current bar, then we trail the stop for an open buy position. If the PSAR price is above the most current bar, then we will trail the stop for an open sell position. In our system, the usage or not of the dynamic trailing with PSAR indicator was evaluated by the GA layer of Phase 2 using a binary gene in the chromosome, which discarded its usage.

**Computing the total net profit.**

The last step of trading simulation layer is the computation of the total net profit. For each open position that is closed, either due to reverse signal triggered by our system or meeting the stop loss or meeting the take profit, a profit or loss is computed. The sum of all the gains/losses in the entire temporal window under consideration for a specific currency pair constitutes our total net profit.

*4.1.2. AI Convolutional Layer*

*4.1.3. The GA layer: a Genetic Algorithm for variables' parameters selection*

The unstable and chaotic structure of exchanges in FX market complicates forecast analysis. This leads to the utilization of optimisation methods. There are many heuristic methods, such as genetic algorithm (GA), simulated annealing (SA), etc. to resolve optimisation problems. Heuristic algorithms are extensively used for solving problems of high computational complexity, alternatively of going via all of the options, which takes up a considerable quantity of time. GA is one of the most popular heuristic optimisation approach that generates options which evolve in time [21]. GA is based totally on evolution and genetics. Heuristic strategies yield nearly but not necessarily optimal solution with reasonable computational effort and time.

Genetic algorithm refers to the heuristic algorithm, which offers an acceptable answer to the hassle in the majority of virtually practically significant cases, however the correctness of the decisions has no longer been tested mathematically, and is used most frequently for problems, the analytical solution of which is very hard or even impossible.

GA contains the concepts, borrowed from nature. These are the ideas of heredity and variability. Heredity is the capacity of organisms to transmit their traits and evolutionary characteristics to their offspring. Thanks to this capability, all living organisms pass the characteristics of their species in their offspring.

The variety of genes in living beings assures the genetic variety of the population and is random, considering nature would not have a manner of knowing in advance which characteristics may be most useful for the future (weather exchange, famine, dryness and so forth.). This variability allows the appearance of creatures with new features, which could live in the new environmental conditions and transmit the new traits to the offspring.

In GA there are two types of variations carried out within the algorithm: (i) the mutation, which is the variability arising due to the emergence of mutations; (ii) combination which arises from the aggregate of genes with the aid of mating.

The *gene* is the basic unit of information transfer: a structural and functional unit of heredity, which controls the development of a particular features or trait. We are able to call one variable of the function the gene. The gene is represented via a actual quantity: a real number. The set of gene-variables of the studied characteristic is the characterizing characteristic of the *chromosome*.

In our approach we have two types of chromosome representation: one associated to rules from technical indicator and one associated to AI-based rule. The chromosome representing rules coming from technical indicators have two types of genes: the genes associated to the technical indicator and the genes associated to the trade.

Let's provide an example: the chromosome representation of the Slow Stochastic Oscillator rule is illustrated in Table 1, where the period $K$, the period $D$ and *Slowing* are the genes directly related to the oscillator, while the genes representing the interval of the stop loss, $intervalSL$, the multiplier factor of take profit with respect to stop loss, $takeProfitXSL$, the money management risk in percentage, $risk\%$, the trailing of the current price by a specified number of points, $trailingStop$, and the minimum profit for activating the trailing stop, $minProfit$, are the genes related to the trade.

| K | D | Slowing | intervalSL | takeProfitXSL | risk% | trailingStop | minProfit |
|---|---|---------|------------|---------------|-------|--------------|-----------|
| 10 | 3 | 6 | 5 | 2 | 2 | 500 | 700 |

Table 1: Chromosome representation of the Slow Stochastic Oscillator rule.

Instead, the chromosome representing AI-based rule has only genes associated to the trade, since all the machine model parameters (e.g. model weights) are computed already during training time of the model. As an example, the chromosome will contain only the genes $intervalSL$, $takeProfitXSL$, $risk\%$, $trailingStop$ and $minProfit$.

All samples of the identical evolutionary era are mixed into a population. Furthermore, the population is arbitrarily divided into two identical colonies: the parent and the descendant colonies. Due to crossing the parental species, which are decided on from the whole population, and different operators of the GA, there is a colony of offspring, which is identical to half the scale of the population.

In our work, the GA algorithm layer is implemented within the MetaTrader 5 platform [7]. Hereafter we report the steps on how the GA layer works:

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[7]https://www.metatrader5.com/en/trading-platform

1. Firstly, a range of values as function of start-stop-step values is defined for each gene of a chromosome.

2. Secondly, the chromosomes which represent the parameter combos are randomly generated to shape an initial proto-population.

3. Thirdly, for each chromosome the fitness value is simulated and computed by the Trading Layer.

4. Finally, we run the main loop of the GA until the selected number of offspring iterations are generated:

   - Making ready the population for reproduction, after disposing of chromosome duplicates.

   - Isolation and protection of the reference chromosome (with the best fitness cost).

   - For each mating and mutation, new parents are picked up on every time, getting ready the population for the subsequent era.

   - Evaluation of genes of the best offspring with the genes of the reference chromosome. If the chromosome of the best offspring is higher than the reference chromosome, then replace the reference chromosome.

We experimented with several parameters' values in order to tune the GA. For sake of clarity, there are no universal parameters' values, and it is a good practice to assign them on the basis of the domain. We varied the scale of the population, which range between 64 and 256, and the threshold value of the epochs number. We did not choose too large values, since this did not accelerate finding solution to the problem. As a result, we have observed the subsequent parameter settings for GA pretty exceptional for our problem (Table 2):

| | |
|---|---|
| **Number of chromosomes in the colony** | 100 |
| **Number of epochs without progress** | 50 |
| **Probability of mutation of each gene in %** | 5 |

Table 2: GA parameter settings.

The following optimization criteria were considered for GA and used with the fitness metric:

- Balance max - the highest value of the balance.

- Net Profit max - the highest value of the net profit.

- Expected Payoff max - a statistically calculated value showing the average return of one deal.

- Drawdown max - difference between the initial deposit and the minimal level below initial deposit throughout the whole testing period.

- Recovery Factor max — the highest value of the riskiness of the strategy, i.e. the amount of money risked by the Expert Advisor to make the profit it obtained.

- Sharpe Ratio max — the highest value of the efficiency and stability of a strategy. It reflects the ratio of the arithmetical mean profit for the position holding time to the standard deviation from it.

For our GA layer, we decided to use as fitness metric the net profit. In conclusion, the output of the GA layer is a chromosome which has the greatest fitness value discovered.

### 4.2. Phase 2: selecting and combining profitable rules

From the first phase we get for each trading rule, both from technical indicators and AI-based, the best chromosome which has the best fitness value. The rules whose best chromosome does not have a positive net profit are directly eliminated and do not pass to this second phase, where the qualified rules are combined to form a trading system. Two layers are used for the selection of the combo trading rules: GA layer and again the Trading Simulation layer, as employed in the first phase.

As depicted on the right part of Fig. 3, at the beginning the GA layer takes in input trading rules selected from the first phase, then GA generates randomly chromosome candidates. It is important to highlight that in this phase the chromosomes are of a different typology with respect to the first phase, in fact each chromosome represents a different rules selection solution; more details will be revealed in Section 4.2.1. The output of this layer are candidate chromosomes sent to the Trading Simulation layer which simulates their behaviour over the historical training data. The latter layer gives as output the Net Profit provided as the fitness value back to the GA layer. This process is looping until the best chromosomes having the highest Net Profit are obtained.

### 4.2.1. The GA layer: a Genetic Algorithm for selecting combination of trading rules

It is important to stress how the GA layer of this phase differs form the one of the first phase. Here the GA layer is used to combine the qualified rules from the first phase to form a trading system.

| Rule 1 | Rule 2 | Rule 3 | $\cdots$ | Rule N |
|--------|--------|--------|----------|--------|
| 0 | 1 | 0 | $\cdots$ | 1 |

Table 3: Chromosome representation of a candidate rules combination

Hereafter we report the steps on how this layer works:

1. In primis, each chromosome is constituted by the same number of genes as the number of qualified rules from the first phase. Each gene is binary, i.e. represented by either 0 or 1 denoting whether the trading rule is selected to be present in the combination. As an example, the chromosome representation with $N$ trading rules is illustrated in Table 3. In this example, the total amount of combination is $2^N$.

2. Then, the GA layer generates randomly chromosome candidates with the goal to form an initial population.

3. For each of the chromosome generated, we will have the subset of trading rules selected to be present in the combination. For such a subset of trading rules, GA computes the average of the interval of the stop loss, $intervalSL$, the average of the multiplier factor of take profit with respect to stop loss, $takeProfitXSL$, the average of the money management risk in percentage, $risk\%$, the average of the trailing of the current price by a specified number of points, $trailingStop$, and the average of the minimum profit for activating the trailing stop, $minProfit$, of all rules selected in the combination. Such a values are the gene related to the trade taken from each chromosome's trading rule output from the first phase.

4. Thirdly, for each chromosome the fitness value is computed and sent by the Trading Layer.

5. GA goes into the same loop as reported in Section 4.1.3.

The fitness metric is the Net Profit for GA layer; its parameters are the same of the ones presented in Section 4.1.3. This process is looping until the best chromosomes having the highest Net Profit are obtained.

Finally, from this layer we output the one best chromosome which has the best fitness value found so far and represent the final rules combination.

### 4.2.2. Trading Simulation Layer: computing the Net Profit of the rules combinations

This is the final layer which combines the qualified trading rules extracted by the chromosomes to generate buy/sell open position signals similar to a unique trading ensemble rule and forms the combined trading system. A hard voting method is used in this layer.

Hereafter we report the steps on how this layer works:

1. At the beginning, for each qualified trading rules this layer stores the values of the genes $intervalSL$, $takeProfitXSL$, $risk\%$, $trailingStop$ and $minProfit$.

2. Then, for each chromosome the Trading Simulation layer computes the average of these four genes for the activated rules in the chromosome, i.e. the rules whose gene is set to 1.

3. Consequently, to open a position we use an *ensemble* approach with *statistical mode*: we open a buy/sell position if this is the most frequent signal sent by the trading rules active in the chromosome, just like a hard voting classifier. Then the Net Profit is given as output.

4. The rest of the steps executed by this layer are the same as reported in Section 4.1.1.

## 5. Experiments

All our experiments are reproducible with the code of our final implemented expert advisor publicly available [8].

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[8] https://git.l3s.uni-hannover.de/mfisichella/forex

*5.1. Investment Setup*

In our experiments we used the following configuration:

- Our investment was limited to $ 10000.

- For each transaction, we allocated the amount indicated by the money management risk presented in Section 4 with an upper limit to 4% of the current available capital.

- The leverage was set to 1:30.

- The ideal execution for order placement with zero latency during trading execution was chosen.

- We used a demo account with a trading broker [9] simulating the placement of buy/sell positions.

*5.1.1. Evaluation Metrics*

Profit
Total trades
Profit Factor
Expected Payoff
Drawdown in %
Recovery Factor
Sharpe Ratio

*5.2. AI Convolutional Layer*

*5.2.1. Experimental Setup*

*5.2.2. Evaluation Metrics*

*5.2.3. Dataset*

*5.2.4. Results*

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[9]https://www.icmarkets.com/en/open-trading-account/demo/

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