

# Time Series Artificial Neural Network based Classification Model for Asset Trading Strategy

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**Abstract.** Best daily trading strategy is meaningful to investors to obtain the maximum return. Financial market plays a key role in the social development. Sufficient funds are of great significance to promote the development of all sectors of society. From the perspective of investors, their purpose is to obtain the maximum income through investing assets in the market. At the same time, the benefit of investors can attract more investors and funds. However, there are huge risks in investment in financial markets. This is mainly because the changes of assets' prices are very complex, and traders cannot predict the changes of assets' prices. Therefore, it is of great significance for investors to determine the trading behavior according to the historical data of asset's price. Aiming at the problem of asset investment strategy, we study from three aspects: asset value accounting, optimal investment strategy and investment decision prediction. A novel method is proposed to represent trading action based on asset state, which represents the current asset state through a 0-1 variable. Then, the change of state indicates the occurrence of transaction. Based on this variable, we propose an evaluation model of the total value of the asset on every day. By maximizing the value of the combination, we establish an optimization model and the Genetic Algorithm (GA) is used to search the best investment combination. Using the prior information of the price, we first solve the combination of asset states of the investor corresponding to the best trading strategy. Then, taking the sequence of states as the supervision information, an Artificial Neural Network (ANN) based classification model for asset state prediction is established. The historical data of Bitcoin daily price is used to predict the asset state on the current day, to realize the decision-making of daily trading strategy. Extensive experiments have been conducted, and the experimental results verify our model can effectively find potential pattern for asset investment and achieve good profits based on the predict investment decisions.

**Keywords:** Bitcoin; Asset Investment Strategy; Genetic Algorithm; ANN.

## 1. Introduction

The financial market links the fund providers who lack investment opportunities with the demanders of transaction and financing funds, thus improving the efficiency and effectiveness of the economy. The financial market plays an important role in driving the economic development of today's society, attracting a large number of investors to participate in the investment of assets and the trading of financial products. From the perspective of investors, their objective is to obtain the maximum return through right trading decision of asset. However, the changes in the financial market are very complicated. The daily price data changes of assets have noise, nonlinearity and nonstationarity [1-5]. The above phenomenon makes the asset investment face great challenges and risks. Therefore, people are eager to study an effective tool to assist investors to analyze assets [2,3]. Therefore, this paper takes bitcoin as an example to study the asset investment strategy.

The research of bitcoin investment strategy is to design an effective mathematical model, which can accurately judge the current investment behavior (buying, holding, or selling) according to the historical data of bitcoin price changes, to maximize the income of investors. In recent years, blockchain technology has received extensive attention, and bitcoin investment has become an important part of the financial market. Bitcoin is also called digital cryptocurrency. It is a kind of digital currency based on P2P, which is open, transparent, and decentralized. The concept of **Bitcoin** was proposed in 2008 and officially launched in 2009 [6,7]. In recent years, as the price of bitcoin fluctuates greatly, it brings great risks to investors and brings great opportunities. Therefore, it attracted many investors to trade bitcoin. As the price of bitcoin fluctuates violently, there is an

increased risk. It is of great significance to study an effective investment strategy to maximize the return of investors.

Since a tool of investment strategy is important to the investors, many methods [1-5] have been proposed. Nathan Crone utilized ANN, SVM, SANN, and LSTM method to formulate prediction models of Bitcoin price respectively. Justin Xu [2] et. al. use 66 tools of analysis index to extract features of historical daily prices of Bitcoin. Then an ANN network based method is proposed for prediction of Bitcoin price based on projection features of Principal Component Analysis method. Isaac Madan [4] proposed a simple regression method for Bitcoin price prediction based on the time series of Bitcoin price. However, these methods focus on the prediction of Bitcoin price, the accuracy of prediction results of existing methods are not satisfactory.

For the research of asset investment strategy, the key point is to mine the rules in the data of asset price changes, so as to effectively capture the opportunity of asset trading. At present, investors usually predict the future development trend of the market subjectively by analyzing the change trend of the asset price, so as to make the transaction behavior of asset investment. However, the market price data of assets is too complex, which makes the investment behavior of investors full of risks. As shown in Figure 1, the historical data of bitcoin price changes from September 10, 2016 to September 11, 2021 is given. From the price data change curve shown in the figure, we can see that there is no obvious trend in the price change of bitcoin, and the data change is non-linear and non-stationary. Therefore, it is impossible to accurately forecast the asset price in the future. Investors' irrational investment behavior may lead to huge losses.

Since the market is complicated, the traders usually cannot reach the maximum profit. With the development of machine learning methods and computer technology, there is a revolution in assets investment. People pay much effort to design a tool for the best trading strategy [8,9]. Different from subjective trading behaviors, the tools make the decision according to the historical market data. For investment strategy problem of Bitcoin, the mathematical model of trading strategy based on the machine learning method is studied. It is a combination of a set of decisions on daily trading actions. We are going to design a model to decide the action of trader on each day.

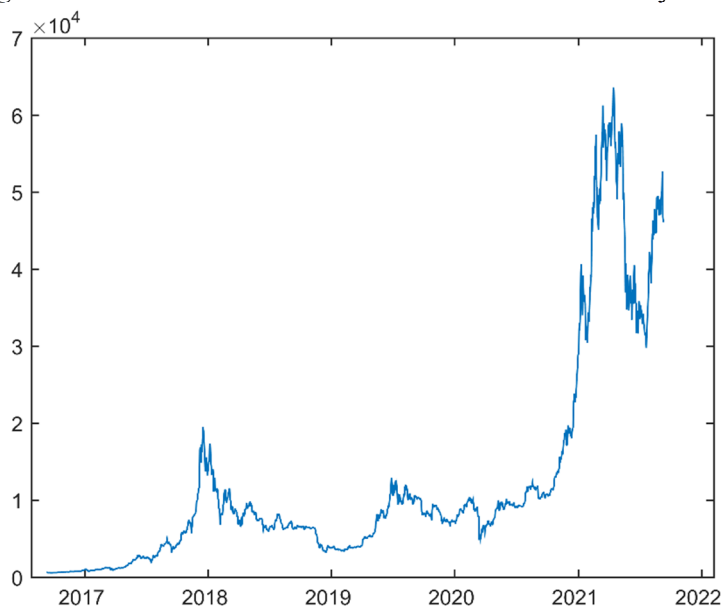


Fig 1. Daily Prices of Bitcoin from 9/11/2016 to 9/10/2021

In this paper, we study on the model of the best trading strategy for investment of Bitcoin asset. The data of daily prices of five years of bitcoin asset is provided. We study on the time series data of daily prices of bitcoin asset for investment strategy problem. We aim to establish an effective method to predict optimal decision of asset investment. However, the best decision investment is related to historical investment actions. And, the best decision of each day is unknown. Besides, there is no other valid information for investment decision. We define the investment strategy problem to a

combination optimization task, and proposed an effective model to search the optimal investment strategy. The combination of optimal investment strategy is used to supervise machine learning based prediction model based on historical daily price data. The contributions of our work are summarized as follows:

(1) A GA method based optimization model for optimal investment strategy is proposed. We first find the best combination of investment actions for investment strategy with maximum benefit. There are three different investment actions (buy, sell, and hold). We define the investment actions by asset state (0: cash or 1: Bitcoin). The final income is formulated to the objective function of optimization model. Moreover, the solution of the proposed optimization model is a combination of asset state. Finally, the optimal investment strategy is solved for historical price data of Bitcoin.

(2) An ANN based investment decision method is proposed. We define the asset state of the optimal investment strategy as the objective. An ANN based regression model and an ANN based classification model are established respectively to prediction the asset state on each day. Then, we obtain the investment action based on the asset states of the current day and the day before.

## 2. Asset Value Accounting Method

In this section, we study on the asset value accounting method for the practical value evaluation under different asset states (cash or Bitcoin). An asset value accounting model is proposed to help the investors to estimate the asset value in real time. It is meaningful to helping investors make right decision on investment behavior (sell, hold or buy).

As we know that the purpose of asset investment strategy model research is to predict the current trading behavior based on historical price data. For this problem, we will use the machine learning method to establish an investment behavior discrimination model, to realize the correct investment. Therefore, we need to first find the optimal investment scheme and learn the investment strategy prediction mode through supervised machine learning method. The key to solving the optimal investment scheme lies in the accounting of asset value. From the perspective of investment behavior only, we assume that the funds used by investors for bitcoin investment behavior are fixed, without considering additional investment or partial withdrawal of funds. Due to the trading behavior of investors, their asset form may change every day, which may be cash or bitcoin. Therefore, we need to calculate their asset value in real time in the form of cash according to the trading behavior of investors.

Given the time series data of prices of Bitcoin  $[x_1, x_2, \dots, x_t, \dots, x_n]$ , where  $x_t$  denotes the price of Bitcoin on the  $t$ -th day. Define  $r$  represent the transaction commission of transactions. In this paper, we set  $r=0.02$ . Let  $z(t)$  denote the total value of investor's asset on the  $t$ -th day, where  $z(0) = a$  represent the initial asset of the investor in cash. Define  $y_t = 0$  or  $1$  denote the asset state of the investor on the  $t$ -th day.  $y_t = 0$  denotes all the asset of the investor are cash. It means that all the asset of the investor is turned into cash at the  $(t-1)$ -th day. We do not consider the gains and losses on the  $t$ -th day. Otherwise,  $y_t = 1$  denotes that all the asset of the investor are Bitcoin. That is to say, all the asset of the investor is turned into Bitcoin at the  $(t-1)$ -th day. In particular, we have  $y_0 = 0$ .

It is worth noting that in practice, investors will have conservative trading behavior in the process of bitcoin trading, that is, they will not buy all bitcoins in cash or sell all bitcoins into cash at one time. However, in this study, we believe that investors have full confidence in the results of the investment strategy model, and both buying and selling will buy all cash into bitcoin or discount all sales. Therefore, there are two states of investors' assets: cash or special ratio. As shown in Figure 2, when the investor's asset state changes between cash and bitcoin, it means buying or selling respectively.

Therefore, the change of investor's asset state with time is represented by sequence  $[y_1, y_2, \dots, y_t, \dots, y_N]$ . When the asset state changes, asset transaction occurs. For the study of asset

investment strategy, we first need to grasp the profit and loss of investors according to their trading behavior. Because the investor's asset state will change between cash and bitcoin with the trading behavior. Therefore, we need to convert the asset value in bitcoin into cash value according to the historical trading behavior of investors, so as to grasp the real-time information of investors' income.



Fig 2. Asset state transfer

According to the asset state transfer mode shown in Figure 2, the investor's asset state changes include the following four situations:

- (1) 0→0: The investor's assets are cash, and there is no trading behavior, and the total value remains unchanged;
- (2) 0→1: The investor's assets are cash, and he will buy all the cash into bitcoin and pay a certain handling fee;
- (3) 1→0: The investor's assets are bitcoin, and he will sell all bitcoin and realize it, and pay a certain handling fee;
- (4) 1→1: The investor's assets are bitcoin, and the total value of bitcoin held varies with the price of bitcoin.

According to the above four situations, the calculation method of asset value is established, as shown in Table 1. In the column of asset value change, the method of asset value change is given, while the recursive formula takes asset state as an independent variable to establish a unified value accounting method based on asset state change.

Table 1. Asset value and calculation methods under 4 investment behaviors

Asset state	Changes of asset value	Recurrence formula
0→0	$z(t) = z(t-1)$	$z(t) = (1-r)^{ 0-0 } \left( 1 + 0 \cdot \frac{x_t - x_{t-1}}{x_{t-1}} \right)^{1- 0-0 } z(t-1) = z(t-1)$
0→1	$z(t) = (1-r)z(t-1)$	$z(t) = (1-r)^{ 1-0 } \left( 1 + 1 \cdot \frac{x_t - x_{t-1}}{x_{t-1}} \right)^{1- 1-0 } z(t-1) = (1-r)z(t-1)$
1→0	$z(t) = (1-r)z(t-1)$	$z(t) = (1-r)^{ 0-1 } \left( 1 + 0 \cdot \frac{x_t - x_{t-1}}{x_{t-1}} \right)^{1- 0-1 } z(t-1) = (1-r)z(t-1)$
1→1	$z(t) = \frac{x_t}{x_{t-1}} \cdot z(t-1)$	$z(t) = (1-r)^{ 1-1 } \left( 1 + 1 \cdot \frac{x_t - x_{t-1}}{x_{t-1}} \right)^{1- 1-1 } z(t-1) = \frac{x_t}{x_{t-1}} \cdot z(t-1)$

To sum up, the accounting model for the total asset value of investors is established as shown in formula (1):

$$z(t) = (1-r)^{|y_t - y_{t-1}|} \left( 1 + y_t \frac{x_t - x_{t-1}}{x_{t-1}} \right)^{1-|y_t - y_{t-1}|} z(t-1) \quad (1)$$

where  $t$  denote time, and  $t \in N^+$ .

### 3. Combination Optimization Model for Optimal Investment Strategy

For investment strategy of Bitcoin problem, we aim to establish a functional relationship between bitcoin historical price data and trading behavior  $y = f(x_t, x_{t-1}, \dots, x_{t-p})$ . where  $(x_t, x_{t-1}, \dots, x_{t-p})$  is the historical prices of Bitcoin in the past  $p+1$  days.  $y$  denotes asset (0: cash, 1: Bitcoin). Therefore, we first need to find the optimal asset state change scheme, and then use the method of machine learning to train a mathematical model that can predict the asset state from the historical data of bitcoin.

In this section, we mainly solve the optimization of investment strategy. In the above, we define the asset state sequence  $[y_1, y_2, \dots, y_t, \dots, y_N]$  to represent an investment strategy, and judge the trading actions such as buy, sell and hold through the change of asset state (0: cash; 1: bitcoin). It is worth noting that the research in this paper is a long-term investment, which needs to find an optimal asset state combination based on the historical data of all bitcoin prices from September 11, 2016 to September 10, 2021. Daily asset state  $\phi(t) = 0$  or 1, so there are  $2^n$  investment schemes ( $n = 1826$  in this paper). Therefore, the essence of the investment strategy optimization problem is to find the investment scheme with the largest return among the  $2^n$  investment schemes, from which we can see that this problem is a typical combination optimization problem. In this paper, GA method will be used to solve the optimal investment strategy problem. The optimization model of the best investment strategy is established as in formula (2):

$$\max z(N) = z(0) \prod_{t=2}^N \left[ (1-r)^{|y_t - y_{t-1}|} \left( 1 + y_t \frac{x_t - x_{t-1}}{x_{t-1}} \right)^{1 - |y_t - y_{t-1}|} \right], \quad (2)$$

*s.t.*  $y_t = 0$  or  $1, t = 1, 2, \dots, N$

where  $N$  denote the length of time series.  $z(0)$  is initial value of investor's asset. The objective function of this optimization task is to maximum the final value of investor's asset.

GA method is a heuristic algorithm designed and proposed by Professor Holland of the United States. It is widely used in optimization problems. The algorithm has good search ability and robustness. The idea of GA method is to express the solution of optimization problem through string coding through the idea of "natural selection and survival of the fittest" in genetics, and then continuously generate new individuals through the process of crossover, mutation, and natural selection, to continuously optimize the quality of individuals in the population and gradually find the optimal solution. The process of crossover and mutation to generate new individuals enables GA method to theoretically obtain all the solutions in the feasible region, while the process of natural selection ensures that the method will quickly converge to the optimal solution and gradually optimize near the optimal solution.

#### 3.1 Genetic Algorithm Design for Asset State Combination Optimization of Maximum Return

##### 3.1.1 Chromosome Coding

GA is an effective method for solving combinatorial optimization tasks. Chromosome coding is the key of GA method, and each chromosome corresponds to a solution of the optimization model. The advantage of GA method is that it can generate new individuals through crossover and mutation, so that chromosomes can obtain all feasible solutions in theory, while the process of natural selection makes the search process converge to the vicinity of the optimal solution quickly, avoiding most unnecessary calculations. In this chapter, we study the asset state combination corresponding to the optimal investment strategy. Asset state is a binary variable. In this paper, cash and bitcoin are represented by 0 and 1 respectively. Therefore, the optimal asset state combination optimization problem is very suitable for genetic coding. Chromosome coding is designed based on solution of objective function. No other transformation operation is required. As shown in Fig. 3, the genetic coding diagram of asset state combination optimization problem is given. Where each value

represents a gene locus, and the chromosome length  $n$  corresponds to the number of days of sample data (the historical data of bitcoin price given in this paper is from September 11, 2016 to September 10, 2021, so  $n = 1826$ ).

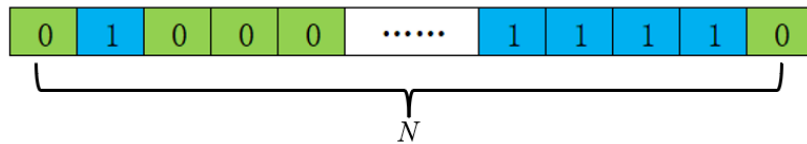


Fig 3. Chromosome coding method

Let  $Popsiz$  denote the size of population.  $N$  denote the length of Chromosome. Based on the above coding method, the matrix  $\mathbf{A}_{Popsiz \times N}$  is defined as a population, wherein each row of the matrix represents an individual. The population initialization method is defined as follows:

$$\mathbf{A}(i, j) = \begin{cases} 1, & \text{if } rand < \alpha \\ 0, & \text{else} \end{cases} \quad (3)$$

where  $rand$  denote a random number between 0 to 1.  $\alpha$  represents the element binarization threshold. In 0-1 coding chromosome initialization, it is usually set  $\alpha=0.5$ .

### 3.1.2 Chromosome Cross Over and Mutation Operations

Chromosome crossover and mutation are the key operations of GA method. Through crossover and mutation, new individuals can be generated, so that the population can continuously search and optimize in the solution space.

Cross operation refers to the cross replacement of gene fragments by chromosomes. First, a gene locus is randomly selected in the chromosome, and then two individuals are randomly selected. With the random gene locus as the crossing point, the first half of the first individual is combined with the second half of the second individual to form a new individual. At the same time, the second half of the first individual is combined with the first half of the second individual to form a new individual. The new individuals obtained by crossing have some characteristics of both parents. The specific principle is:

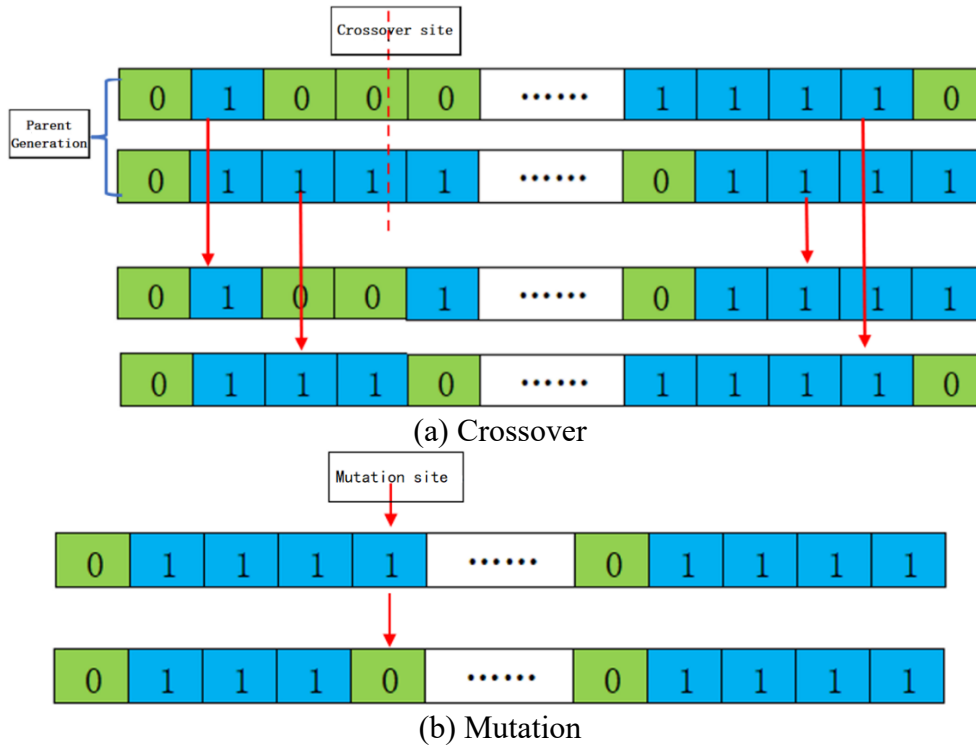
Let  $\mathbf{a}_i = (a_{i1}, a_{i2}, \dots, a_{iN})$  and  $\mathbf{a}_j = (a_{j1}, a_{j2}, \dots, a_{jN})$  denote two different individuals respectively. Generate a site,  $s$ , for cross over operation. Then, we exchange the gene fragments after the  $s$  site of the two chromosomes. Hence, we obtain new individuals of next generation  $\mathbf{a}'_i = (a_{i1}, a_{i2}, \dots, a_{is}, a_{j(s+1)}, \dots, a_{jN})$  and  $\mathbf{a}'_j = (a_{j1}, a_{j2}, \dots, a_{js}, a_{i(s+1)}, \dots, a_{iN})$ .

Mutation is another important operation in GA method. The same as the crossover operation, the purpose of mutation is also to generate new individuals. Unlike the crossover operation, mutation is random. That is to say that not every individual is mutated. The search direction of new individuals generated by mutation is independent of their parents. The specific principle of mutation operation is as following:

We first define  $\theta$  as mutation rate. In this paper, the mutation rate  $\theta$  is set to 0.4. Generate a mutation site  $s$  randomly. Let  $\mathbf{a}_i = (a_{i1}, a_{i2}, \dots, a'_{is}, \dots, a_{iN})$  denote an individual which is mutated. The chromosome of new individual after mutation is  $\mathbf{a}'_i = (a_{i1}, a_{i2}, \dots, a'_{is}, \dots, a_{iN})$ .  $a'_{is}$  is the gene code that is defined as follows:

$$a'_{is} = \begin{cases} |1 - a_{is}|, & \text{if } rand < \theta \\ a_{is}, & \text{else} \end{cases} \quad (4)$$

The principle of crossover and mutation operations are shown in Fig. 4:



**Fig 4.** Crossover and mutation operations

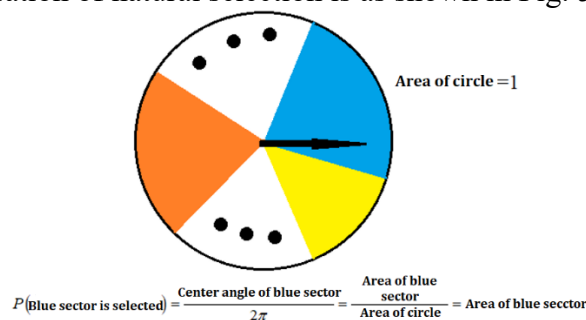
**3.1.3 Natural Selection**

Natural selection is an important step in GA method. The natural elimination mechanism established by natural selection makes it easier for excellent individuals to survive. The principle of "natural selection, survival of the fittest" is adopted for screening, to accelerate the optimization process and gradually optimize near the optimal solution.

Fitness is a key concept in the process of natural selection. It is the value obtained by fitness function based on the solution of individual's chromosome code. The individual with higher fitness value has higher probability to be reserved. Conversely, individuals with lower fitness have lower survival rates. Therefore, it involves two aspects: Determination of fitness function and chromosome selection rules.

Fitness function is a quantitative standard for individual performance. Natural selection determines the probability of "survival" based on the fitness value. The fitness function is designed according to optimization objective function. In this paper, the optimization objective function is the maximum value of the final asset. Therefore, we directly use the optimization objective function as the fitness function to quantify the individual's "viability".

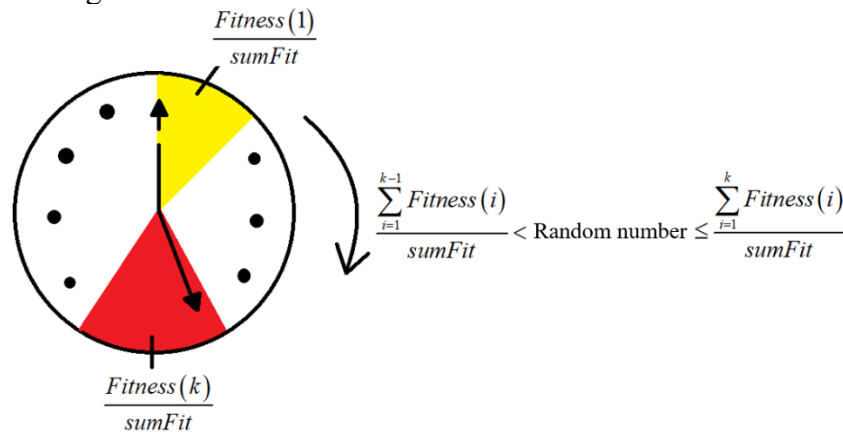
In addition, we use the strategy of "roulette + elite selection" to conduct individual natural selection. Roulette algorithm is also called proportional selection method. Its basic idea is: in a circle with an area of 1, the probability of a point falling on a certain sector is the area of the corresponding sector, the size of the sector area is related to ratio between individual's fitness and the sum of fitness values of all individuals. The operation of natural selection is as shown in Fig. 5:



**Fig 5.** Roulette method of natural selection

This specific operation of roulette method is to randomly generate a random number of  $0 \sim 1$ . The  $k+1$  sector is selected if the random number is greater than sum of ratio of the front  $k$  ( $k \in \mathbb{N}$ ) sectors and less than sum of ratio of the front  $k+1$  sectors. Then,

We use  $\frac{\text{fitness of single individual}}{\text{sum of fitness of total}}$  to define the area of each sector. The area of each sector represents the probability of being selected of each individual. Define the fitness value of the  $i$ -th individual  $\mathbf{a}_i$  as  $Fitness(i)$ . The sum of all fitness value is defined as  $sumFit$ . The specific principle is shown in Fig. 6:



**Fig 6.** Schematic diagram of roulette selection

In addition, for the elite retention strategy, that is, several excellent individuals are retained. This article retains the top 5% excellent individuals.

### 3.2 Calculation Method and Process

The calculation process of the optimal asset state combination problem based on GA method is as follows:

**Step 1:** Initial the parameters, including size of population  $Popsiz$ , iterations number  $G$ , Chromosome length  $N$ , mutation rate  $\theta$ , transaction commission  $r$ , and Bitcoin price change sequence  $[x_1, x_2, \dots, x_t, \dots, x_N]$ .

**Step 2** (chromosome coding and population composition):  $Popsiz$  initial chromosomes were generated to form the initial population.

**Step 3** (Cross over): For the arrangement of all staining weights, two adjacent ones form a pair (not repeated). A locus is selected for two chromosomes in each pair, and the first locus is partially exchanged with this locus to form a new population.

**Step 4**(mutation): For every chromosome in the new population, take a certain real number  $k$ . if it is less than, take a component of this chromosome for mutation operation (i.e., 0, 1 exchange). Otherwise, no operation will be performed on this chromosome. After all chromosomes were taken, a new population was formed.

**Step 5** (natural selection): The initial population and the new population were merged, and the fitness function value of individual was calculated, and  $Popsiz * 0.95$  individuals were screened by the roulette method. Besides, select the top  $Popsiz * 0.05$  individuals and combine them to form a new population.

**Step 6:** Select the individual with the highest fitness and record its fitness;

**Step 7:** Judge whether the iteration number  $G$  is reached. If yes, go to step 8; otherwise, return to step 3 as the starting population;

**Step 8:** for the fitness of the best individual of each generation, draw the convergence curve of algebra and fitness, and output the fitness of the final best individual and its corresponding trading strategy.

The specific flow of the calculation method is shown in Fig. 7:

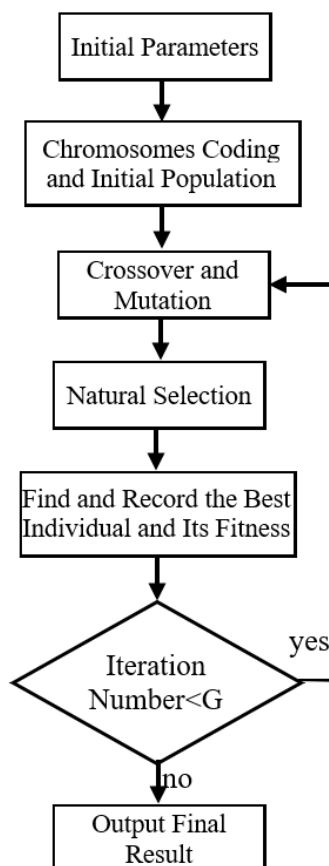


Fig 7. Steps of GA method

### 3.3 Experimental Results and Analysis

In this part, we solve the optimal investment strategy by programming. By Matlab programming, we search the optimal asset state combination scheme.

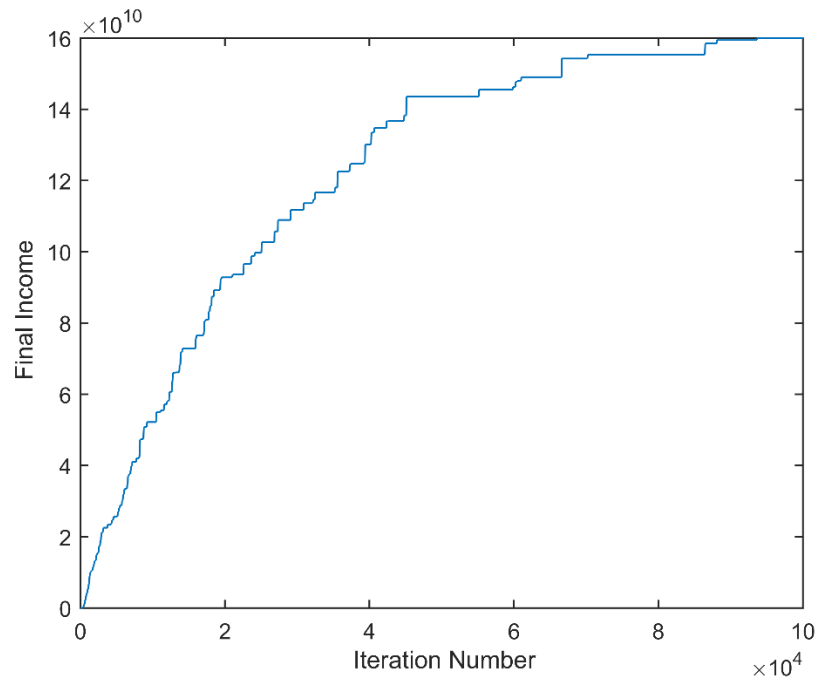
#### 3.3.1 Dataset and Parameters Setting

In this paper, the investment strategy research is based on the real data of the historical daily price of Bitcoin from 11/9/2016 to 10/9/2021. Unlike other assets (gold, non-ferrous metals, etc.), bitcoin trading is 24 hours a day, 7 days a day, and there is no holiday closure. Therefore, bitcoin price data is continuous time series data (as shown in Fig. 1).

For parameter setting, the number of iterations is set as  $G = 100000$ . The size of population is set to  $Popsiz=1100$ . The mutation rate is set as  $\theta=0.4$ .

#### 3.3.2 Optimal Solution and Convergence Analysis

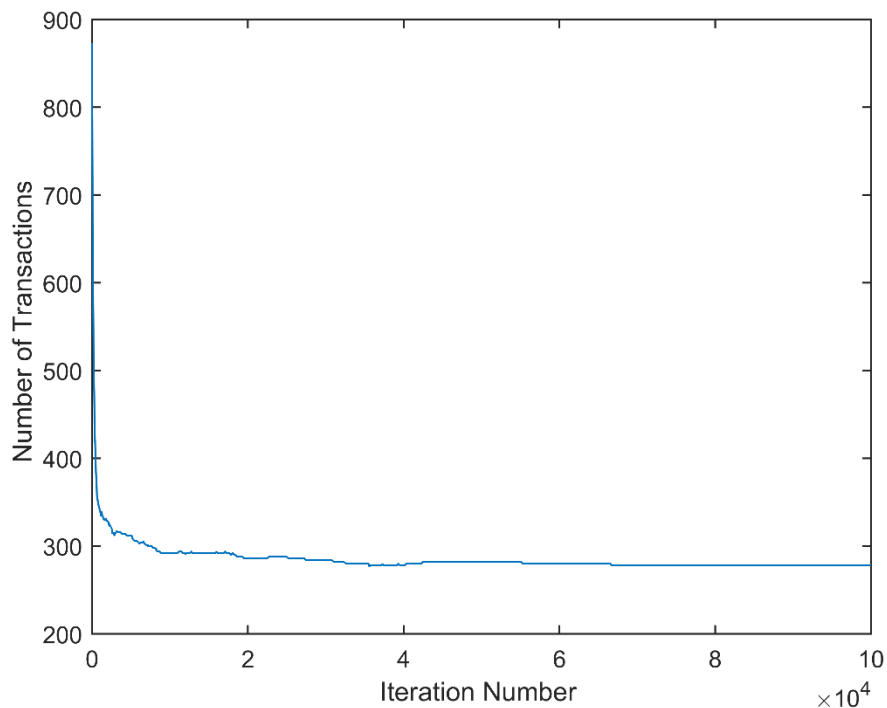
According to the parameter settings given above, the GA method is introduced to find the optimal solution of the asset state combination scheme. The convergence results of the income and the number of iterations is shown in Fig. 8, which shows the fitness function value of the optimal individual in each iteration. According to the results as displayed in Fig. 8, the optimal solution of best asset state combination is obtained through 100000 iterations in this paper, and the fitness function of the optimal individual in the population rapidly converges from 0 to the optimal solution. Thus, the GA method has a good effect on searching the solution of the optimal asset state combination problem, and can accurately and quickly find the optimal solution from  $2^{1826}$  combinations.



**Fig 8.** Convergence curve of income

### 3.3.3 Relationship between Objective Function and Transaction Times

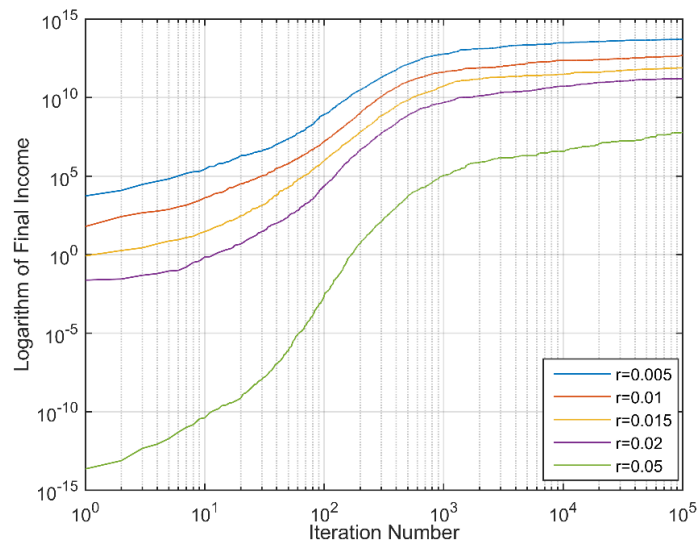
According to the parameter settings given above, the GA method is introduced to search the solution of best asset state combination. The convergence result of the number of transactions and the number of iterations are shown in Fig. 9, which shows the number of transactions of the optimal individual in each iteration. The results in the Fig.9 shows that the solution of the best asset states combination is obtained through 100000 iterations in this paper. The number of transactions of the optimal individual in the population rapidly decreases from about 880 and converges to a certain value near 280, which indicates that too many transactions will lead to less returns. At the same time, it can also be seen that the genetic algorithm has a good effect in solving the optimal asset state combination problem.



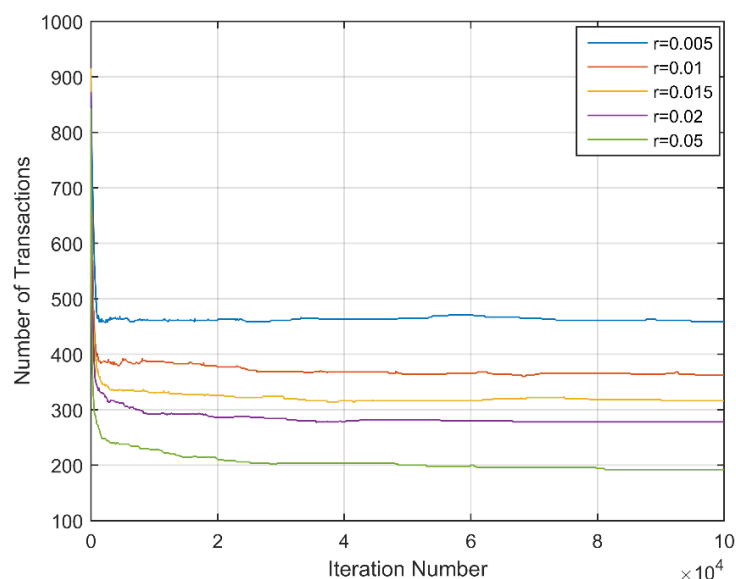
**Fig 9.** Convergence curve of transaction number

### 3.3.4 Sensitivity Analysis Transaction Times and Transaction Commission

According to the analysis in section 4.3.3, the number of transactions is an important factor affecting the final value of investor's asset, and the number of transactions converges rapidly with the increase of iteration times. This shows that too many transactions will seriously affect the final income. This is mainly because each transaction will generate a certain handling fee, and the handling fee is charged according to the proportion of the transaction volume. It can be inferred that the value of transaction rate  $r$  is an important parameter that affects the optimal investment strategy and the final income. In this regard, this paper analyzes the sensitivity of the optimal trading strategy to the rate. Under different settings such as  $r = 0.005, 0.01, 0.015, 0.02$  and  $0.05$ , the optimal solution is obtained, and the optimal solution and the number of transactions is compared. The results of Fig. 10. Fig. 10 (a) shows the convergence curve of the logarithm value of the final asset value under different rates. Fig. 10 (b) displays the curve of the number of transactions under different rates along with increasing of iteration numbers. According to results in the Fig. 10, the final asset value of the best asset state combination gradually decreases with along the increase of the transaction commissions, and the number of transactions also decreases. This is consistent with the actual situation. The higher the rate, the higher the cost of each transaction. As the rate increases, the transaction frequency should be reduced.



(a) Convergence curve of income under different transaction commission values



(b) Convergence curve of trading number under different transaction commission values

**Fig 10.** Comparison of results under different transaction commission values

## 4. Prediction Method of Optimal Investment Strategy

### 4.1 Data Preprocessing

In this paper, we study the asset investment decision based on the historical price data of bitcoin. According to the actual situation, the original bitcoin price change data fluctuates sharply. Therefore, in this paper, the data is preprocessed first, and the price change data is converted into the price growth rate change data. The processing method is as follows:

$$x'_t = \frac{x_t - x_{t-1}}{x_{t-1}} \quad (5)$$

The data is preprocessed based on MATLAB programming, and the processed results are shown in Fig. 11 below:

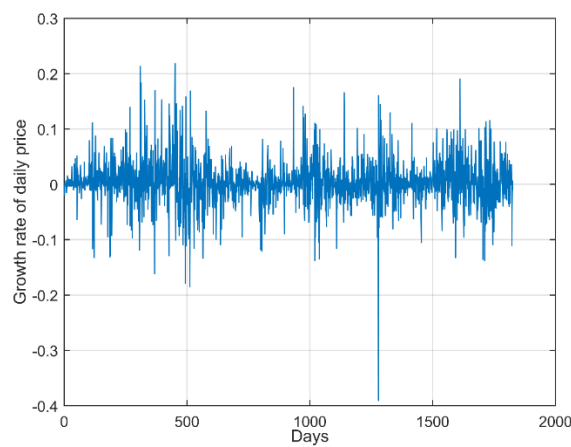


Fig 11. Data after preprocessing

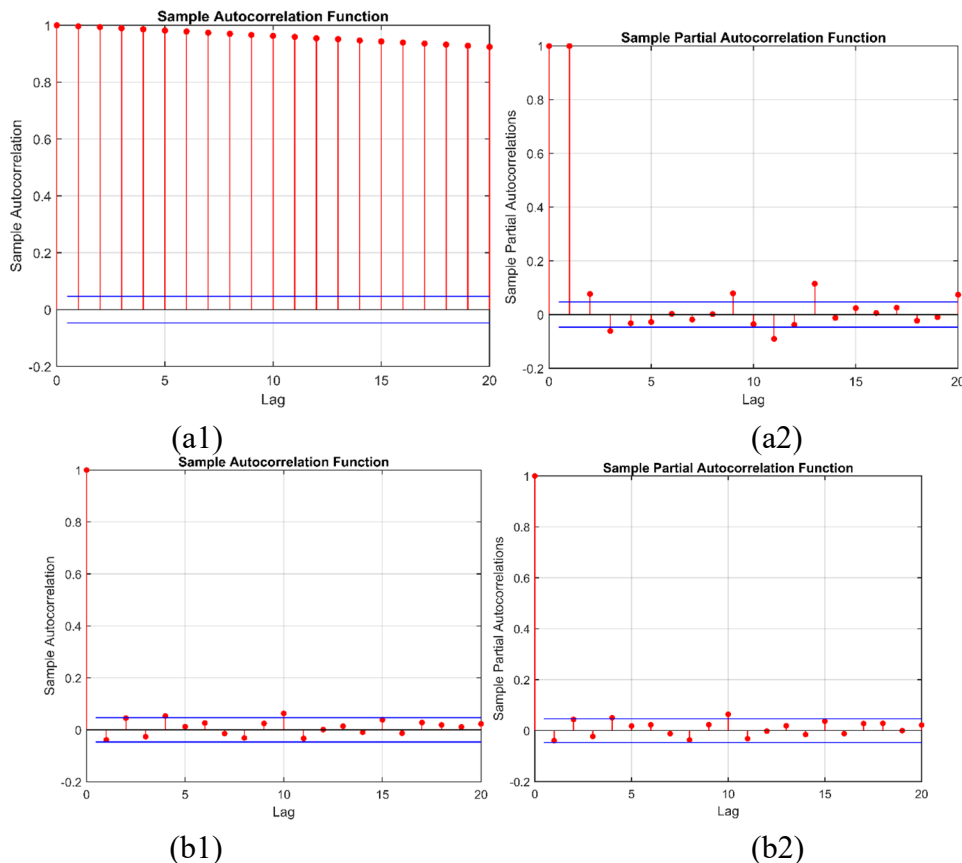


Fig 12. Autocorrelation and partial correlation analysis

Further, a stationarity test is performed on the preprocessed data. We conducted autocorrelation and partial correlation tests on the original data and the preprocessed data respectively, and the results are shown in Fig. 12 below. The autocorrelation test results of the original data are given in (a1) and (a2), and the partial correlation test results are given in (b1) and (b2). The results in the Fig. 12(b1) and (b2) that the data after preprocessing has good stationarity and is suitable for time series analysis. In addition, according to the partial correlation analysis of raw data preprocessed in Figure 12 (a2) and figure 12 (b2), the price change rate of bitcoin has certain periodicity.

## 4.2 Regression based Method for Investment Action Prediction

### 4.2.1 Multiple Linear Regression Model

Through the data preprocessing method above, we get the time series data of bitcoin price increase rate  $\{x'_2, x'_3, \dots, x'_N\}$ . In the above, the time series of asset state is defined as the investment action. In section 3, the optimal asset state combination is solved by GA method. Let  $\{y_2, y_3, \dots, y_N\}$  denote asset states of the best investment strategy. In this section, we aim to design a regression model to model the pattern of predicting right asset state from historical price data and asset states. We formulate the regression model as in equation (6):

$$y_t = \beta_0 + \beta_1 x_{t-1} + \beta_2 x_{t-2} + \dots + \beta_p x_{t-p} + \varepsilon$$

$$\min E(\beta) = \sum_{t=p+1}^N (\hat{y}_t - y_t)^2 \tag{6}$$

Where  $\beta = (\beta_0, \beta_1, \dots, \beta_p)$  is regression coefficient of regression model. And  $\hat{y}_t = \beta_0 + \beta_1 x_{t-1} + \beta_2 x_{t-2} + \dots + \beta_p x_{t-p}$ .

In equation (6), we use multiple linear regression to formulate the relationship between Bitcoin price and right investment action. Solve the regression model of formula (6) by least square method. The results are shown in Table 2.

**Table 2.** Result of regression model

Constant	x1	x2	x3	x4	x5	x6	x7	R2	F	sig.
0.607	-0.35	-0.001	-0.03	0.1	1.16	1.83	4.98	0.20	31.2	8.60E-39

According to the result in Table 2, the goodness of fit of the regression model is bad. This means that there is big error between multiple linear regression function and ground truth data. While, according to the result of F-test, p-value = 8.60E-39 is far less than 0.01. That is to say that the regression model is significant. We use the regression model to prediction the asset state and establish prediction method based on the estimation result of regression model as in equation (7):

$$z_t = \begin{cases} 0, & \text{if } \hat{y}_t \leq \alpha \\ 1, & \text{else} \end{cases} \tag{7}$$

where  $\alpha$  denote the threshold for asset state judgement.  $\alpha$  is defined by mean of regression value of training data as in equation (8):

$$\alpha = \frac{1}{N'} \sum \hat{y}_t \tag{8}$$

where  $N'$  denote number of training samples. We evaluation the performance of the regression model by test on the historical data of Bitcoin. The experimental result of regression model is displayed in Table 3. There are 1819 days historical data of Bitcoin. They are randomly divided into 2 equal parts. 910 days of data are treated to training data, and the rest 909 days of data are treated to test data.

**Table 3.** Confusion Matrix of prediction result of regression model

	Training data				Teat data			
		Target Class				Target Class		
		0	1			0	1	
Output Class	0	278 30.6%	53 5.8%	84.0% 16.0%	0	249 27.4%	81 8.9%	75.5% 24.5%
	1	198 21.8%	380 41.8%	65.7% 34.3%	1	170 18.7%	409 45.0%	70.6% 29.4%
		58.4% 41.6%	87.8% 12.2%	72.4% 27.6%		59.4% 40.6%	83.5% 16.5%	72.4% 27.6%

**4.2.2 Multiple Linear Regression Model**

In the section above, we use the multiple linear regression model to establish relationship between historical price data and asset state. However, we should note that the importance of asset states is different from days. Therefore, we use weight linear regression model to establish the relationship between historical price data and asset state. The define the weights of data on each day as in equation.

$$w_t = \frac{z(\mathbf{y}')}{z(\mathbf{y})} \tag{9}$$

where  $\mathbf{y} = (y_1, y_2, \dots, y_t, \dots, y_N)$  and  $\mathbf{y}' = (y_1, y_2, \dots, y'_t, \dots, y_N)$  denote the optimal asset state combination and changed asset state combination.  $y'_t = |1 - y_t|$ . Then, we establish weighted multiple linear regression model as in formula (10):

$$y_t = \beta_0 + \beta_1 x_{t-1} + \beta_2 x_{t-2} + \dots + \beta_p x_{t-p} + \varepsilon$$

$$\min E(\boldsymbol{\beta}) = \sum_{t=p+1}^N w_t (\hat{y}_t - y_t)^2 \tag{10}$$

Also, we use least square method to solve the regression model in equation (10). The objective function of formula (10) can be transformed into formula (11) in vector-matrix form:

$$\min E(\boldsymbol{\beta}) = \frac{1}{2} (\boldsymbol{\beta}\mathbf{X} - \mathbf{Y})^T \mathbf{W} (\boldsymbol{\beta}\mathbf{X} - \mathbf{Y}) \tag{11}$$

where  $\mathbf{W} = \text{diag}(w_1, w_2, \dots, w_N)$  is weight matrix. Let  $\mathbf{X} = (\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_N)$  and  $\mathbf{Y} = (y_1, y_2, \dots, y_N)$  denote the sample data and label information respectively. Differentiate the objective function  $E(\boldsymbol{\beta})$ , then we have,

$$\frac{\partial E(\boldsymbol{\beta})}{\partial \boldsymbol{\beta}} = \mathbf{X}^T \mathbf{W} (\boldsymbol{\beta}\mathbf{X} - \mathbf{Y}) = \mathbf{X}^T \mathbf{W} \boldsymbol{\beta}\mathbf{X} - \mathbf{X}^T \mathbf{W} \mathbf{Y} \tag{12}$$

Let  $\frac{\partial E(\boldsymbol{\beta})}{\partial \boldsymbol{\beta}} = 0$ , we get

$$\boldsymbol{\beta} = (\mathbf{X}^T \mathbf{W} \mathbf{X})^{-1} \mathbf{X}^T \mathbf{W} \mathbf{Y} \tag{13}$$

According to the method in equations (13), we calculate the parameters of the weighted regression model. The result of fitting of this regression model is displayed in Table 4. The goodness of fit of weighted linear regression model  $R^2=0.16$ . It is worse that the linear regression model in formula (6). The result of F-test  $p\text{-value} = 0.00 < 0.1$ . Therefore, this model is significant.

**Table 4.** Result of regression model

Constant	x1	x2	x3	x4	x5	x6	x7	R2	F	sig.
0.621	-0.163	0.55	-0.12	0.61	0.989	1.94	3.96	0.160	24.50	1.10E-30

Following the experiment method in section 4.2.1, we predict asset states by weighted linear regression model and the result is as displayed in Table 5. As shown in this table, accuracy of the predicted result of weighted linear regression model is worse than linear regression model. The total accuracy of prediction result are 71.4% on both training data and test data. This is because of that the weighted linear regression model weight the data of different days with different values. The asset states cause more benefits will be more valued. The results in Table 3 and Table 5 only display accuracy of prediction result. In section 4.2.3, the final returns of these two methods will be displayed to analyze the effects of these two different methods.

**Table 5.** Confusion Matrix of prediction result of regression model

	Training data				Teat data				
		Target Class				Target Class			
		0	1			0	1		
Output Class	0	267 29.4%	52 5.7%	83.7% 16.0%	0	240 26.4%	102 11.2%	70.2% 29.8%	
	1	209 23.0%	382 42.0%	64.6% 35.4%	1	157 17.3%	409 45.0%	72.3% 27.7%	
		56.1% 43.9%	88.0% 12.0%	71.4% 28.6%			60.5% 39.5%	80.0% 20.0%	71.4% 28.6%

### 4.2.3 Comparison Result and Analysis

In this section, the final profits of predicted asset states combinations of traditional linear regression method and weighted linear regression method are displayed as in Table 6. The initial capital is set to  $z(0)=20000$ . Transaction commission is set to  $r=0.02$ . According to the result displayed in Table 6, the weighted regression model achieves better profit than traditional linear regression method.

**Table 6.** Comparison result of different methods

	Number of Transactions	Final Asset Value
Linear Rgression	530	51243
Weighted Linear Regression	502	91414

### 4.3 Time Series ANN Model based Regression Method for Investment Strategy

ANN model is a classical machine learning algorithm, which has a good effect in classification, recognition, regression, and other tasks. Through a large number of parameters and nonlinear transformation (activation function), this method makes the model have a good fitting effect to the nonlinear functional relationship [6].

The basics of ANN method is the operation of neuron. Neuron operation transforms input data by linearly weighting and biasing input variables. Then, the output result is obtained by a nonlinear activation function. There are many neurons in ANN structure. The input variables will be transformed by the patterns of neurons to get many outputs. Thus, ANN method can fully mine the

functional relationships in the data. The commonly used activation functions are *sigmoid* and *tanh*[10,11].

Let  $\mathbf{x} = (x_1, x_2, \dots, x_m)$  denote vector of input variables. Define  $\mathbf{w} = (w_1, w_2, \dots, w_m)$  denote the vector of weights corresponding to the input variables. Besides, we define  $b$  denote the bias of a neuron. We select *sigmoid* to the activation function. Then, the mathematical expression of operation of each neuron as in equation (14):

$$y = \text{sigmoid}(\mathbf{w}^T \mathbf{x} + b). \tag{14}$$

The mathematical expression of *sigmoid* is as in equation (15).

$$\text{sigmoid}(x) = \frac{1}{1 + e^{-x}} \tag{15}$$

The ANN model uses multiple neurons constructing a network to get many nonlinear transformed features. The nonlinear properties of neuron and structure of ANN network make the model more powerful than multiple linear regression model in extracting the complex relationship between historical price data and trading action.

In this section, we establish a 3-layers time series ANN network for prediction of asset state as shown in Fig. 3. The mathematical expression of this model is as in equation (16):

$$h_i(x_{t-1}, \dots, x_{t-d}; y_{t-1}, \dots, y_{t-d}) = g\left(\sum_{k=1}^d w_{ik}^{(1)} x_k + \sum_{k=d+1}^{2d} w_{ik}^{(1)} y_{k-d} + b_i^{(1)}\right) \tag{16}$$

where  $g(\cdot)$  is activation function.  $h_i(x_{t-1}, \dots, x_{t-d}; y_{t-1}, \dots, y_{t-d})$  denotes the output of the  $i$ -th neuronal node.  $b_i$  denotes the bias of the  $i$ -th neuronal node. According to the equation (16), the time series ANN based model formulate the relationship between historical price data, asset state and current asset state. At the hidden layer, we choose the *tansig* activation function as in equation (17).

$$g(x) = \frac{2}{1 + e^{-2x}} - 1 \tag{17}$$

Then, the output values of hidden layer will be input into the output layer to predict asset state value  $y = 0$  or  $1$ . The prediction method is as in equation (18).

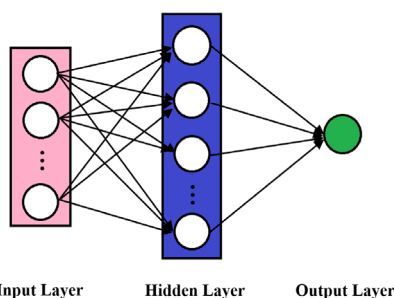
$$y = f\left(\sum_{j=1}^s w_j^{(2)} h_j + b\right) \tag{18}$$

where  $w_j^{(2)}$  denote the weight of the  $j$ -th neuronal node.  $h_j$  denote the input value of the  $j$ -th neuronal node.  $b$  denote the bias of output layer.  $f(\cdot)$  denote the activation function of output layer. We select the sigmoid function as activation function.

The ANN network train the parameters with stochastic gradient descent method. In this model, we choose the MSE loss function for model training. The loss function is as in equation (19).

$$\min E = \sum_{t=T}^N (y_t - \hat{y}_t)^2 \tag{19}$$

where  $\hat{y}_t$  denote the predicted value of asset state.



**Fig 13.** Structure of ANN network

We model the time series ANN network structure for asset state prediction as follows,

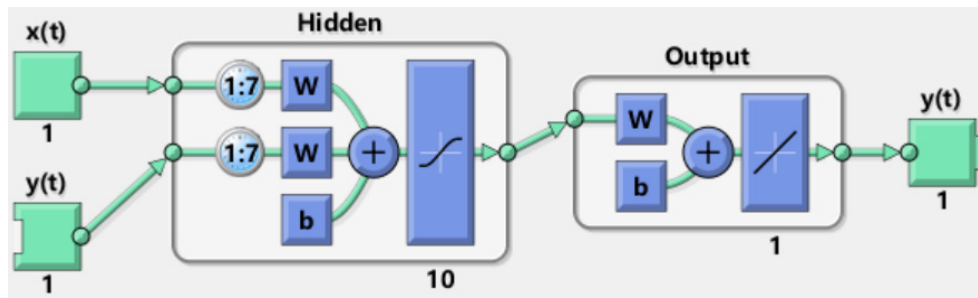


Fig 14. ANN network of asset state regression model

For asset state estimation, we use the prediction value  $\hat{y}_t$  to formulate the final asset state prediction result as in equation (20).

$$\tilde{y}_t = \begin{cases} 1, & \text{if } \hat{y}_t > \alpha \\ 0, & \text{else} \end{cases} \quad (20)$$

where  $\alpha$  denote the threshold for asset state judgement.

#### 4.4 Time Series ANN Model based Classification Method for Investment Strategy

In section 4.3, we establish a regression model based on time series ANN network for asset state prediction. While, the asset state is defined by a 0-1 variable. Therefore, the period historical data and asset state could be transformed into a classification task according to asset state value. We use the common 0-1 vectors to represent the label of class as in formula (21).

$$y_t = \begin{cases} (1,0), & \text{if cash} \\ (0,1), & \text{elseif Bitcoin} \end{cases} \quad (21)$$

As in formula (21) we use a one-hot vector to represent investor's asset state on the  $t$ -th day. And we establish the time series ANN based classification model as in Fig. 15.

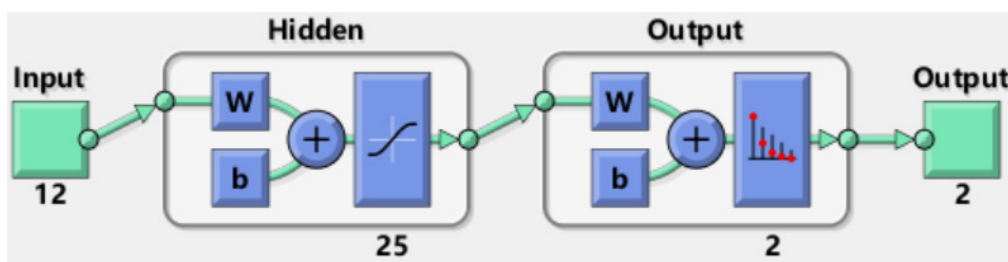


Fig 15. Time series ANN based classification model for asset state

## 5. Experiment

In this paper, the investment strategy problem is ingeniously transformed into the optimization problem of asset state combination. According to the optimal asset state obtained in Section 4 and the time-series data of Bitcoin price increasing rate obtained in Section 5.1, set the period  $T = 7$ , that is, predict the current asset state using the historical data of the past 7 days. The result of time series ANN method based regression model is displayed as in Fig. 16. And, the result of time series ANN method-based classification model is as displayed in Table 7.

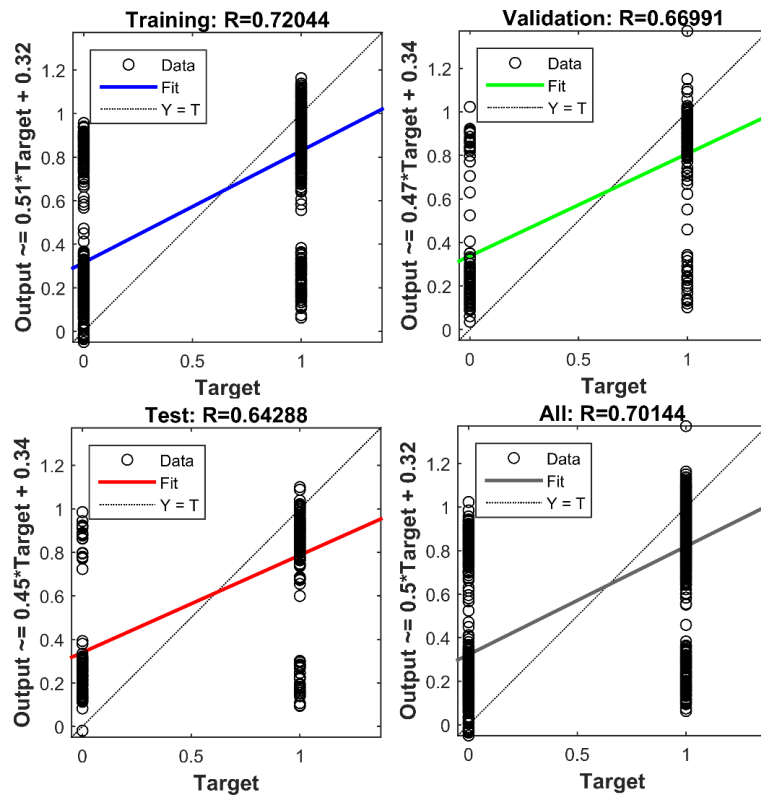


Fig 16. Regression result of time series ANN based regression model

Table 7. Confusion Matrix of prediction result of regression model

	Training data				Validation data				
		Target Class				Target Class			
		0	1			0	1		
Output Class	0	367 28.8%	96 7.5%	79.3% 20.7%	0	73 26.7%	27 9.9%	73.0% 27.0%	
	1	93 7.3%	717 56.3%	88.5% 11.5%	1	19 7.0%	154 56.4%	89.0% 11.0%	
		79.8% 20.2%	88.2% 11.8%	85.2% 14.8%			79.3% 20.7%	85.1% 14.9%	83.2% 16.8%
	Test data				Total data				
		Target Class				Target Class			
		0	1			0	1		
Output Class	0	87 31.9%	9 3.3%	90.6% 9.4%	0	527 29.0%	132 7.3%	80.0% 20.0%	
	1	20 7.3%	157 57.5%	88.7% 11.3%	1	132 7.3%	1028 56.5%	88.6% 11.4%	
		81.3% 18.7%	94.6% 5.4%	89.4% 10.6%			80.0% 20.0%	88.6% 11.4%	85.5% 14.5%

According to the result shown in Fig. 16. The ANN network has better performance than linear regression method on prediction of asset state. The goodness of fit R2 equals to 0.49. According to the results in Table 7 displays confusion matrix of time series ANN method-based classification

model. The ANN algorithm can accurately predict the optimal asset state, with an accuracy rate of 85.5%. Especially, the accuracy rate on test data reaches to 89.4%.

Moreover, we summarized prediction result as in Table 8. As shown in this table, the ANN model reaches better profits. Besides, it should be note that the ANN model uses 70% data for training and 15% data for validation and 15% data for test.

**Table 8.** Comparison results of two ANN models

	Accuracy	Final asset value
ANN Regression Model	85.48%	43996409414.7
ANN Classification Model	85.50%	52533540151.5

## 6. Conclusion

Best daily trading strategy is meaningful to investors to obtain the maximum return. Financial market plays a key role in the social development. Sufficient funds are of great significance to promote the development of all sectors of society. From the perspective of investors, their purpose is to obtain the maximum income through investing assets in the market. At the same time, the benefit of investors can attract more investors and funds. However, there are huge risks in investment in financial markets. This is mainly because the changes of assets' prices are very complex, and traders cannot predict the changes of assets' prices. Therefore, it is of great significance for investors to determine the trading behavior according to the historical data of asset's price. However, designing the best daily trading strategy model is very difficult. This is mainly because we don't know the number of transactions (purchase / selling). Therefore, how to use mathematical symbols to correctly represent the overall investment scheme has become the key to establish the best daily trading strategy model. For best investment action combination of historical data, we proposed a novel approach to represent the investment action. This approach defines asset state (cash or Bitcoin) by 0-1 variable. The change of asset state is used to represent investment action. Based on this variable, we propose an evaluation model of the total value of the asset on every day. By maximizing the value of the asset, we establish an GA based optimization model. Using the prior information of the price, we first solve the asset states combination of the investor corresponding to the best trading strategy. Then, taking the sequence of states as the supervision information, a state classification prediction model based on artificial neural network is established, and the historical data is used to predict the model, so as to realize the decision-making of daily trading strategy. Finally, the proposed prediction model is test on the historical price data of Bitcoin. And the experimental results proved that our method could effectively find the best pattern for making Bitcoin trading decisions.

## Acknowledgments

From 2020, I began to learn computer programming, and I became very interested, especially in various computing methods. From then on, I used my spare time and holidays to get knowledge of machine learning and artificial intelligence algorithms. Later, in the math class of the second year of senior high school, I was very lucky to be a student of Mr. Chen Yiling. I was lucky to follow Mr. Chen to learn trigonometric function, derivative, limit, solid geometry, probability, sequence, analytic geometry and other mathematical knowledge. During my study with Mr. Chen, I took the initiative to chat with Mr. Chen and established a good relationship. Because during the Spring Festival and the Spring Festival, I listened to my parents and family talk about college and work, which made me start to think about what I should study in college, what major and what job I should choose. After a period of understanding, I found that I didn't know much about what I wanted to learn in college, which is quite different from what I learned in middle school. Knowing that Mr. Chen is a doctor of mathematics, I asked him a lot of questions, especially about the application of mathematics.

Teacher Chen graduated from the Department of Mathematics of Shanghai Tongji University with a doctor's degree in applied mathematics. At present, Mr. Chen works in Shanghai Gezhi middle school as a math teacher. Mr. Chen has rich scientific research experience and has published many papers on SCI, EI and domestic core journals. His main research fields including partial differential equations, optimal portfolio theory, etc.

In the chat with Mr. Chen, I was more interested in portfolio and optimization. Especially, my parents would also make some stock investments in financial management after work. But I think the changes of stock data are so complicated. Whether there is any information to refer to is just like buying lottery tickets. It depends on luck. At the same time, I also found that the process of stock investment is very relevant to the knowledge of portfolio explained by Mr. Chen. During the Spring Festival, I heard my parents and elders chat about Bitcoin. Although I didn't understand it very much, I felt very interesting. In particular, I was very excited by the news that many people became rich and broke overnight by investing in Bitcoin. So I used my spare time to learn relevant knowledge from Mr. Chen. Under the encouragement of Mr. Chen, he tried to use mathematical methods to research investment. At the beginning, Mr. Chen asked me to collect some data on the price of bitcoin. Later, he began to guide me step by step. I found that mathematical knowledge can do a lot of things, and in the process of learning, I found that many of the things I have learned now are still very simple. After more than half a year of study and teacher Chen's patient guidance, I finally completed the research on Bitcoin investment methods. Especially for the writing of papers, Mr. Chen helped me revise and review them again and again.

Here, I would like to express my gratitude to Mr. Chen for his patient guidance, which not only enabled me to learn a lot of knowledge, but also made me more interested in learning, especially in mathematics.

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