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Control Charts-based Trading Strategies for Cryptocurrency and Stock indices

Course: Data Analytics and Systems Monitoring

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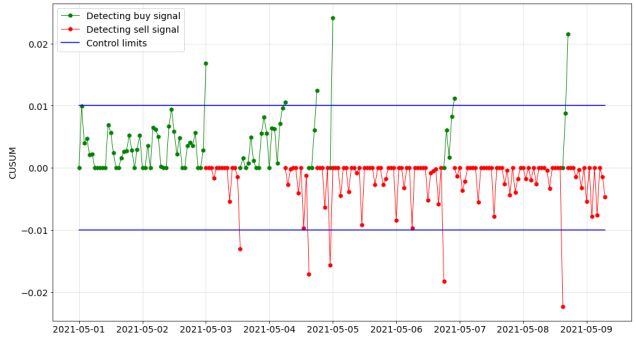
Problem

Is it possible to determine some strategies by control charts to trade and make profit? If yes, which control chart or method works the best?

Our focus is on Application of Control Charts in Cryptocurrency and stock prices.



Problem

Motivation for Cryptocurrency:
Cryptocurrency is one of the most controversial topics nowadays and we want to see if we can use the control charts to make profit in this market.

Motivation for risk-adjusted CUSUM:
By applying risk adjusted monitoring method, we try to reveal factors that affect the stock price which is exclusive to the company instead of the whole industry.

- Better than fundamental analysis

Literature

Paper	Main Focus/ Idea/ Methods	Connections/Differences	Comments
Roberts HV. Stock-market "patterns" and financial analysis: methodological suggestions. *J Finance*. 1959;14(1):1-10.	First paper that used SPC methods to study changes in stock market price levels.	No trading rules	Set up control limits to aid visualize analysis in the future. If a point falls outside the control limits, this gives a signal for analyst.
Hubbard CL. A control chart for postwar stock price levels. *Finance Anal J*. 1967;23(6):139-145.	Determined stock price trend and compared it with gross national product (GNP) and personal income trends. Set up decision rules for buying or holding stocks.	Proposed a decision rule based on sell and buy signals.	The used data is monthly values of 200 stock average from 1950 to 1967.
Alexander SS. Price movements in speculative markets: trends or random walks. Ind Manag Rev. 1961;2(2):7-26. 43. Alexander SS. Price movements in speculative markets-trends or random walks, number 2. Ind Manage Rev. 1964;5(2):25–46.	Introduced the filter trading rules. Filter trading rule is defined as a sequence of signals for buying and selling stocks. Buy signal: for example, the daily closing price of a stock moves up at least a certain percent x from a subsequent low. x here is the filter size for the trading rule.	Calculated profits from various filter sizes and compared them with buy and hold strategy.	Findings in these papers can be summarized as: Price changes appear to follow a random walk over time, but a move, once initiated, tends to persist.

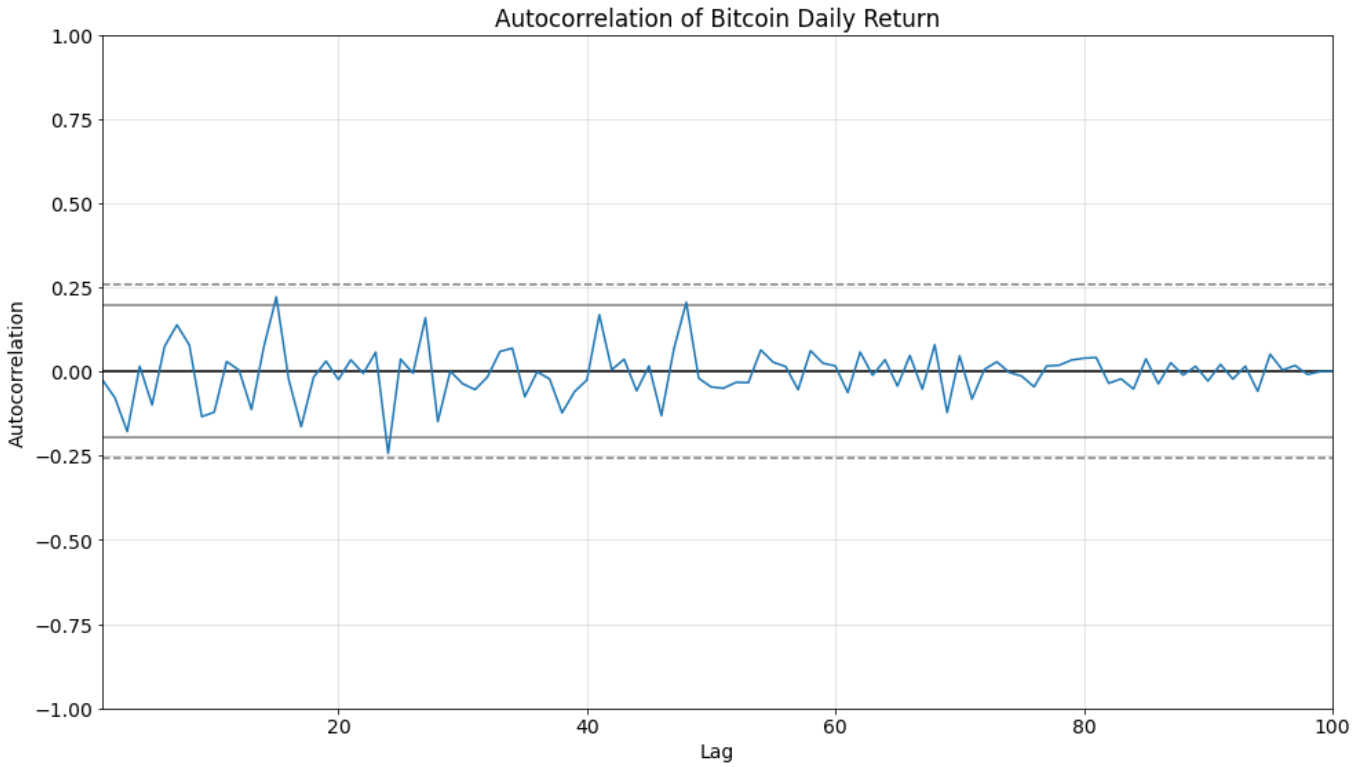
Literature

Paper	Main Focus/ Idea/ Methods	Connections/Differences	Comments
Lam K, Yam H. CUSUM techniques for technical trading in financial markets. *Finadndc Eng Jpn Markets*. 1997;4(3):257-274.	Motivated by the filter trading rule, used **CUSUM** to create a trading strategy (equivalent to filter trading rule) in the stock market. a) k=0, h=log(1+x) x: filter size of trading rule= b) Then generalized the classical filter trading rule: k≠0 First, they considered general CUSUM procedure (k>0, h=0)	First Trading Strategy based on CUSUM method. Worked on different scenarios for k and h.	Main drawback of the general filter trading rule (k>0, h=0): Absence of a stop-loss mechanism.
YiG,Coleman S, RenQ. CUSUM method in predicting regime shifts and its performance in different stock markets allowing for transaction fees. *J Appl Stat*. 2006;33(7):647-661.	CUSUM techniques in predicting regime shifts (between bullish and bearish) + transaction fees. Performance of each k and h is measured by Total Profit and Daily Profit.	Considering transaction fees in contrast with Lam, Yam. For the first time in CUSUM papers.	Result of considering transaction fees was Deterioration of CUSUM (No acceptable k and h)

Methods

Deal with Auto-correlated data

1. Calculate and use Return of each coin, which is not auto-correlated.



Methods

Deal with Auto-correlated data

2. Another procedure we use to deal with this auto-correlated data is using ARIMA. Find the best AR and MA parameters for our case. Implement CUSUM model on the residuals. (Residual-based CUSUM).

Auto ARIMA takes into account the AIC and BIC values generated **to determine the best combination of parameters**. AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion) values are estimators to compare models. The lower these values, the better is the model.

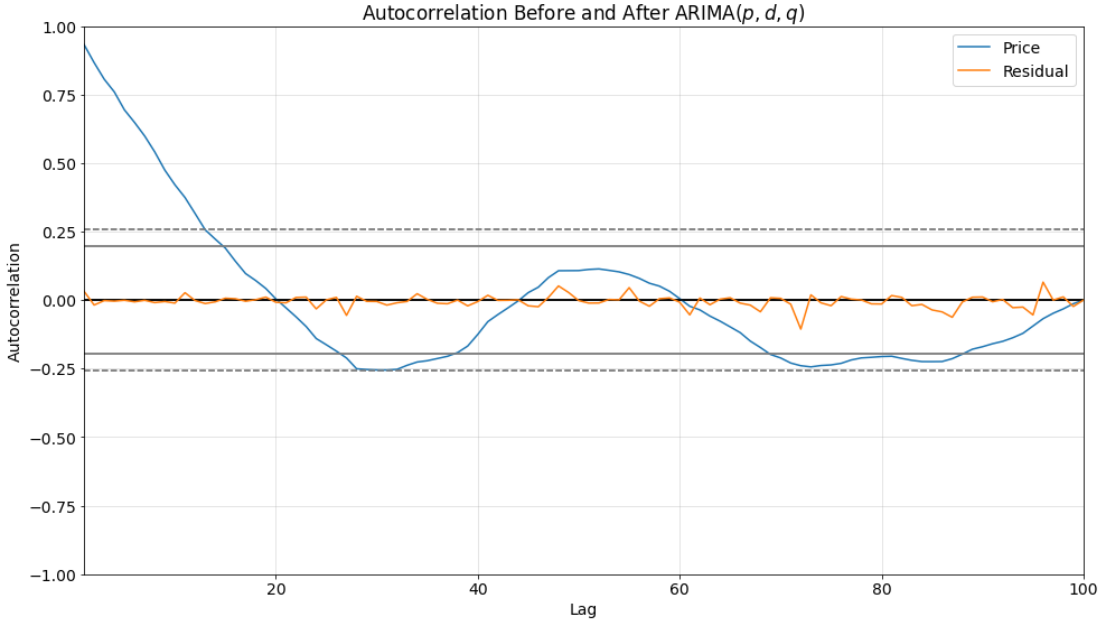
Auto ARIMA parameters: (1, 0, 2)

SARIMAX Results

Dep. Variable:	price	No. Observations:	2952
Model:	ARIMA(1, 0, 2)	Log Likelihood	-21803.056
Date:	Wed, 01 Dec 2021	AIC	43616.113
Time:	21:46:33	BIC	43646.064
Sample:	05-01-2021 - 08-31-2021	HQIC	43626.895
Covariance Type:	opg		

	coef	std err	z	P>|z|	[0.025	0.975]
const	4.067e+04	6625.485	6.139	0.000	2.77e+04	5.37e+04
ar.L1	0.9992	0.001	1209.364	0.000	0.998	1.001
ma.L1	0.0255	0.011	2.291	0.022	0.004	0.047
ma.L2	-0.0441	0.013	-3.493	0.000	-0.069	-0.019
sigma2	1.521e+05	1678.180	90.652	0.000	1.49e+05	1.55e+05

Ljung-Box (L1) (Q):	0.00	Jarque-Bera (JB):	13659.23
Prob(Q):	0.95	Prob(JB):	0.00
Heteroskedasticity (H):	0.32	Skew:	-0.89
Prob(H) (two-sided):	0.00	Kurtosis:	13.39



Methods

1. CUSUM

a) Source: Montgomery Model

$$C_i^+ = \max[0, x_i - (\mu_0 + K) + C_{i-1}^+]$$

$$C_i^- = \max[0, (\mu_0 - K) - x_i + C_{i-1}^-]$$

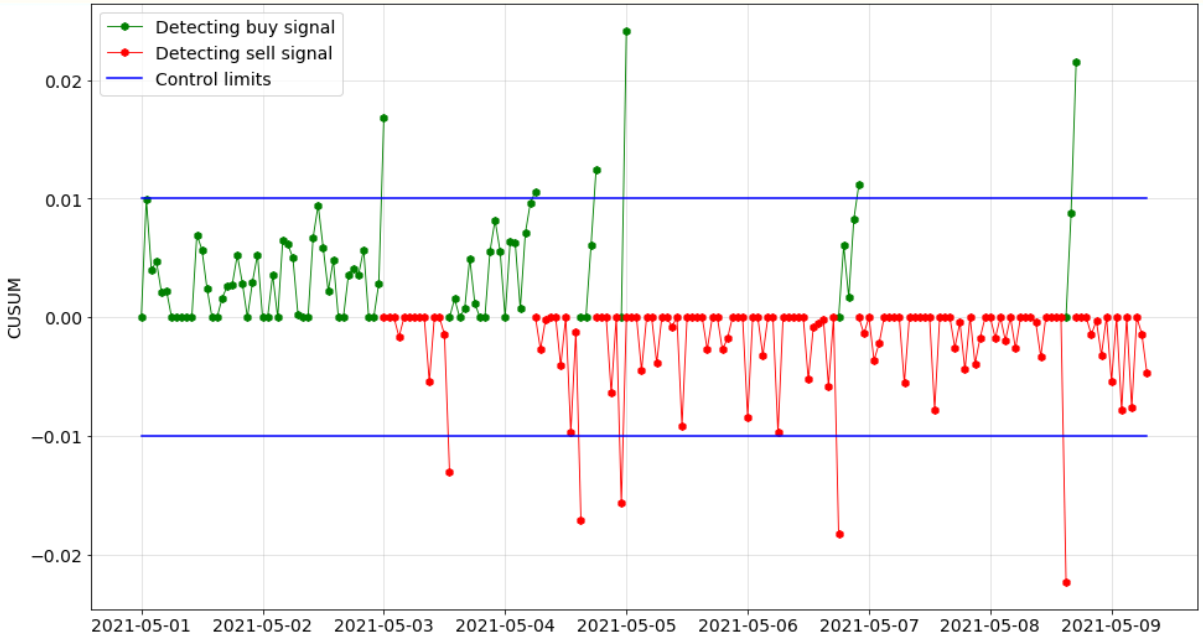
$$C_0^+ = C_0^- = 0$$

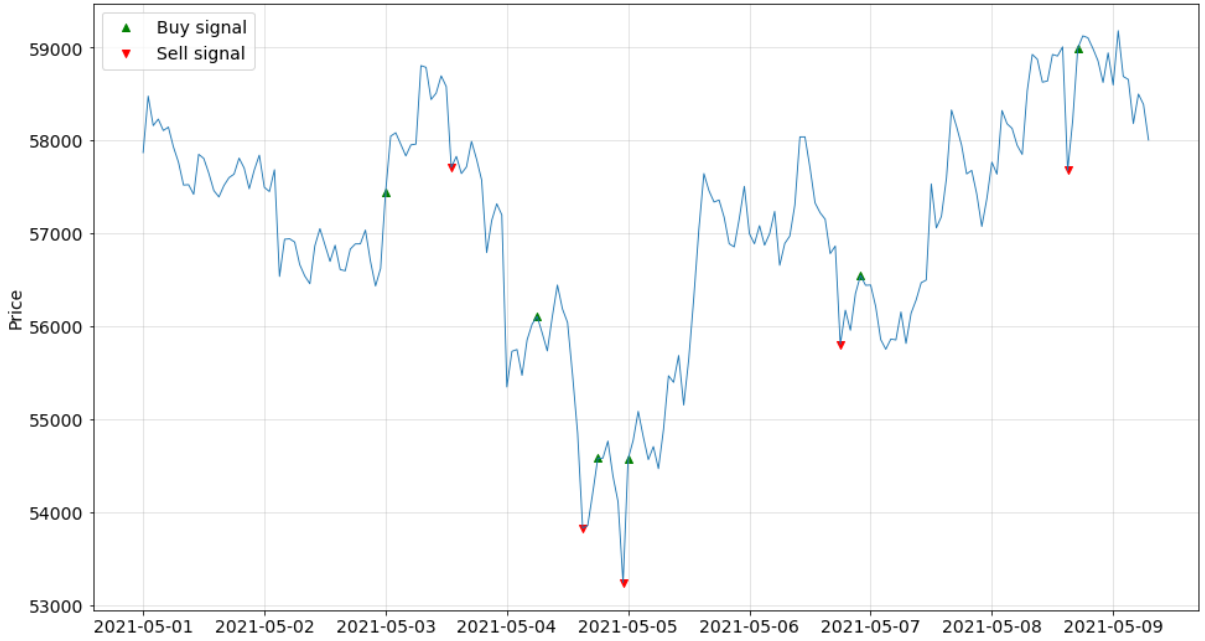
b) Source: **Yi *et al* (2006)**

$$r_i = \log(\frac{x_i}{x_{i-1}})$$

$$C_i^+ = \max[0, r_i - K + C_{i-1}^+]$$

$$C_i^- = \min[0, r_i - K + C_{i-1}^-]$$

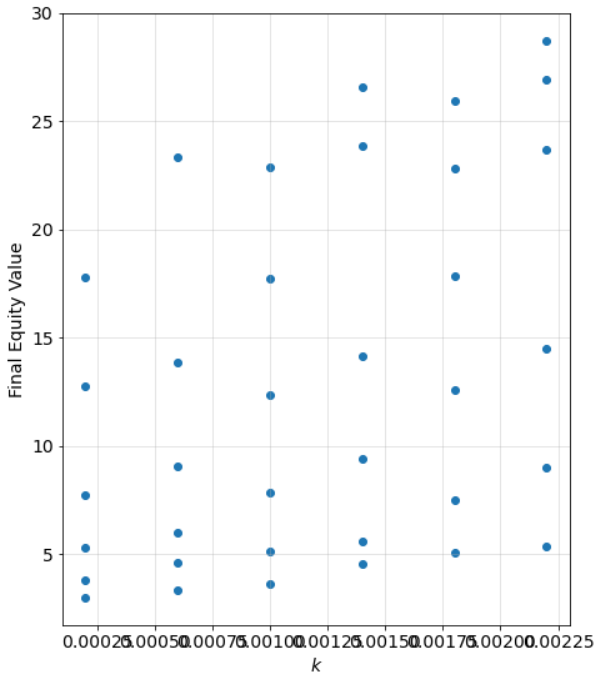

Detecting buy signal
Detecting sell signal
Control limits
CUSUM
0.02
0.01
0.00
−0.01
−0.02
2021-05-01
2021-05-02
2021-05-03
2021-05-04
2021-05-05
2021-05-06
2021-05-07
2021-05-08
2021-05-09

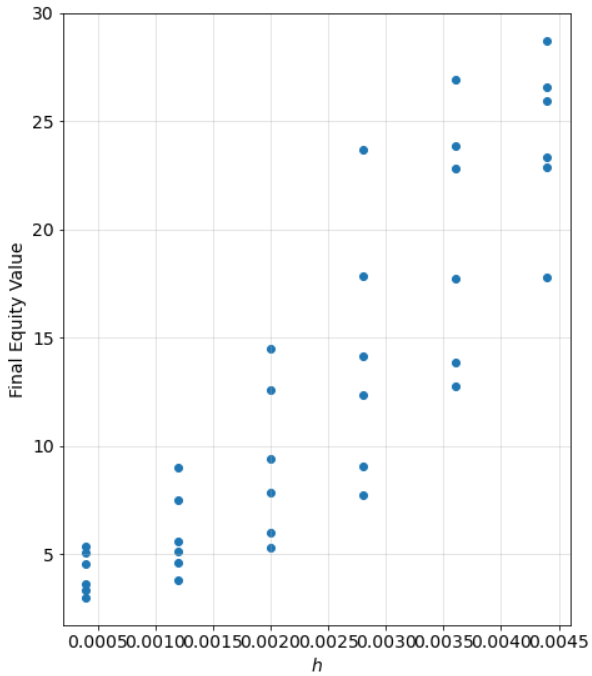

Buy signal
Sell signal
Price
59000
58000
57000
56000
55000
54000
53000
2021-05-01
2021-05-02
2021-05-03
2021-05-04
2021-05-05
2021-05-06
2021-05-07
2021-05-08
2021-05-09

Methods

K and h Values

To find the best trading strategy, we use grid search for different pairs of k and h values. We compare the investment returns of each (k, h) and then we can present the best k and h for each method.





Methods

Transaction fees:

Most of the papers did not consider the transaction fees in their model, but to be more realistic, we consider transaction fees which is currently 0.5% of each buying transaction. We add this transaction fees to our models and compare the profits we make with and without it in Results.
(Return as feature, Montgomery Model for CUSUM)

Transaction fee in reality:
Coinbase pricing and fees disclosures: 0.50%

https://help.coinbase.com/en/coinbase/trading-and-funding/pricing-and-fees/fees#
https://help.coinbase.com/en/pro/trading-and-funding/trading-rules-and-fees/fees

Methods

2. EWMA

$$Z_0 = \mu_0 \text{ (estimated)}$$

$$Z_i = \lambda x_i + (1 - \lambda) Z_{i-1}$$

$$UCL_{Z_t} = \mu_0 + L\sigma\sqrt{\frac{\lambda}{(2-\lambda)n}[1-(1-\lambda)^{2t}]}$$

$$LCL_{Z_t} = \mu_0 - L\sigma\sqrt{\frac{\lambda}{(2-\lambda)n}[1-(1-\lambda)^{2t}]}$$

Need to mention that after each buying signal, we reset our EWMA control chart and hold the security until we get a sell signal (To prevent short.)

Methods

Why not risk-adjusted on Cryptocurrency?

Unlike cryptocurrencies, stocks are directly linked to companies under regulatory surveillance. Investors can potentially use the information on the company and industry to reduce the risk of volatility.

Risk-adjusted CUSUM for stock market

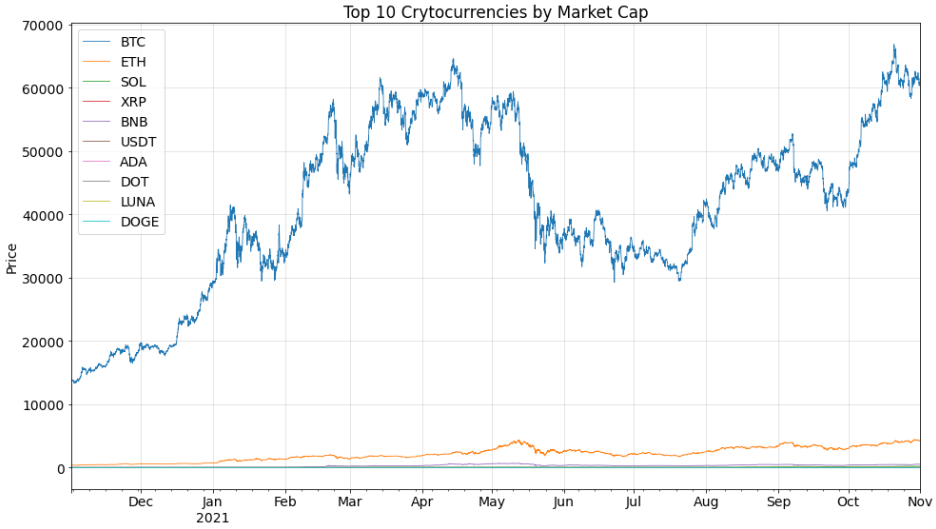
Linearly regress BioTech company stock on its industry indices.
Apply CUSUM to the residuals.

➔ Adjust biomedical company stock price by industry trend to reveal the real operations performance of the company.

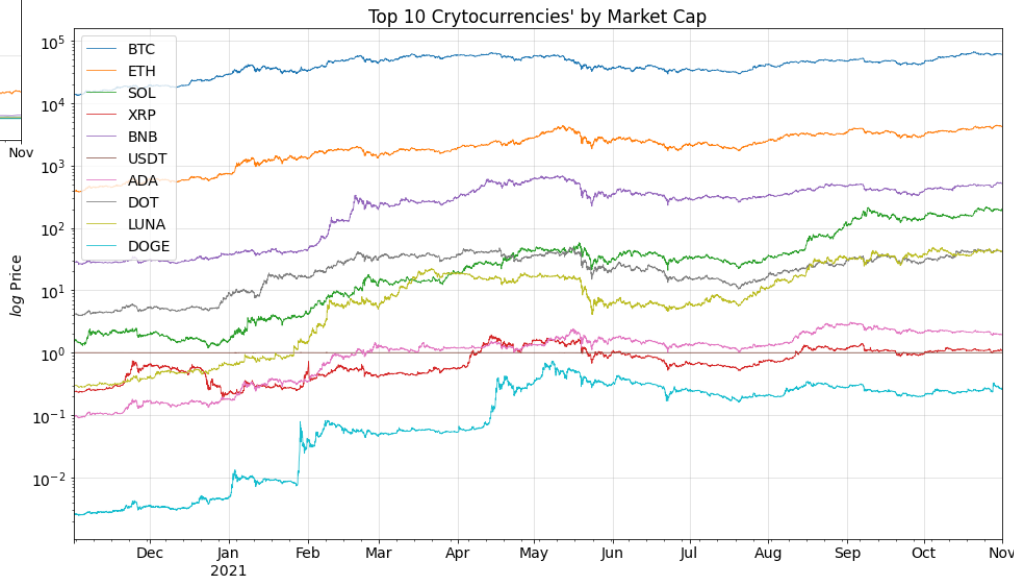
Data

In this project we use two data:

1. Historical hourly crypto price for top 9 Coins (Ranked by market cap)+Dogecoin for six months.



CRYPTO COMPARE



Data

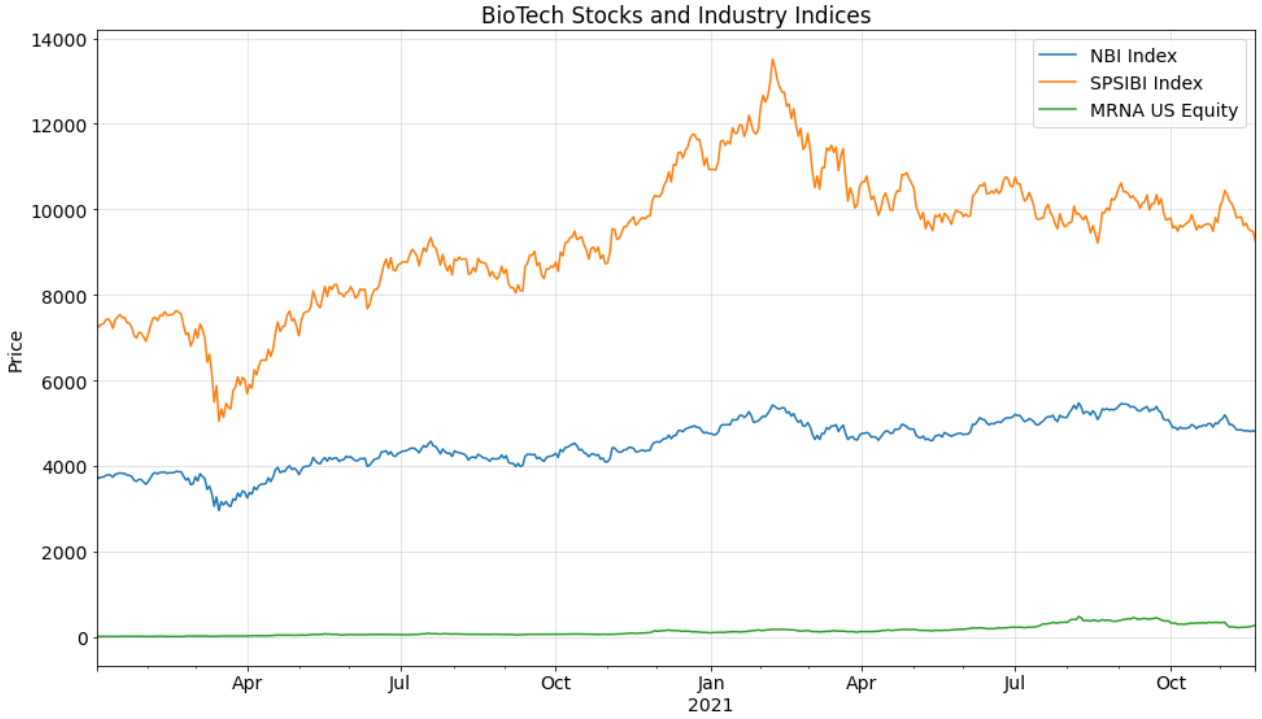
2. Biotech Stock Market data is brought from Bloomberg:

Indices

DJI Index: Dow Jones Industrial Average. 30 prominent companies listed on stock exchanges in the United States.
SPX Index: Standard and Poor's 500. 500 large companies listed on stock exchanges in the United States.
NBI Index: NASDAQ Biotechnology Index. 213 Biotechnology or the Pharmaceutical industry companies listed on NASDAQ.
SPSIBI Index: S&P Biotechnology Select Industry Index. The biotechnology sub-industry portion of the S&P Total Markets Index (S&P TMI).

US Equities

PFE US Equity: Pfizer Inc. American multinational pharmaceutical and biotechnology corporation headquartered on 42nd Street in Manhattan, New York City.
MRNA US Equity: Moderna Inc. Pharmaceutical and biotechnology company based in Cambridge, Massachusetts that focuses on RNA therapeutics, primarily mRNA vaccines.
JNJ US Equity: Johnson & Johnson. Consumer Health, Pharmaceutical, and Medical Devices.



Results Structure

1. CUSUM
    a) Return
        i. Montgomery CUSUM Model
            This is the only case we compare w/wo Transaction Fees
        ii. Literature CUSUM Model

    b) Price/Residual based CUSUM (Handle autocorrelation with ARIMA):
        i. Montgomery CUSUM Model
        ii. Literature CUSUM Model

2. EWMA
    a) Return
    b) Price/Residual based EWMA (Handle autocorrelation with ARIMA)

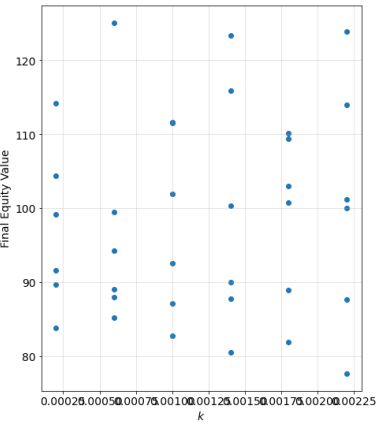
3. Risk-adjusted CUSUM for stock market data

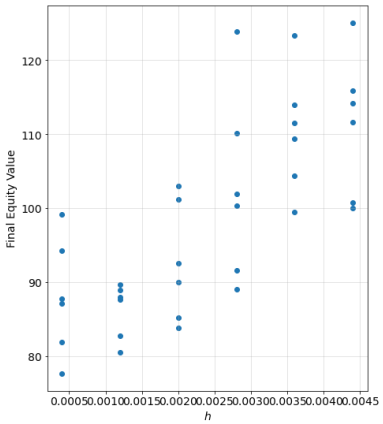
4. Back test

To be completely realistic, Transaction Fee is considered unless stated otherwise.

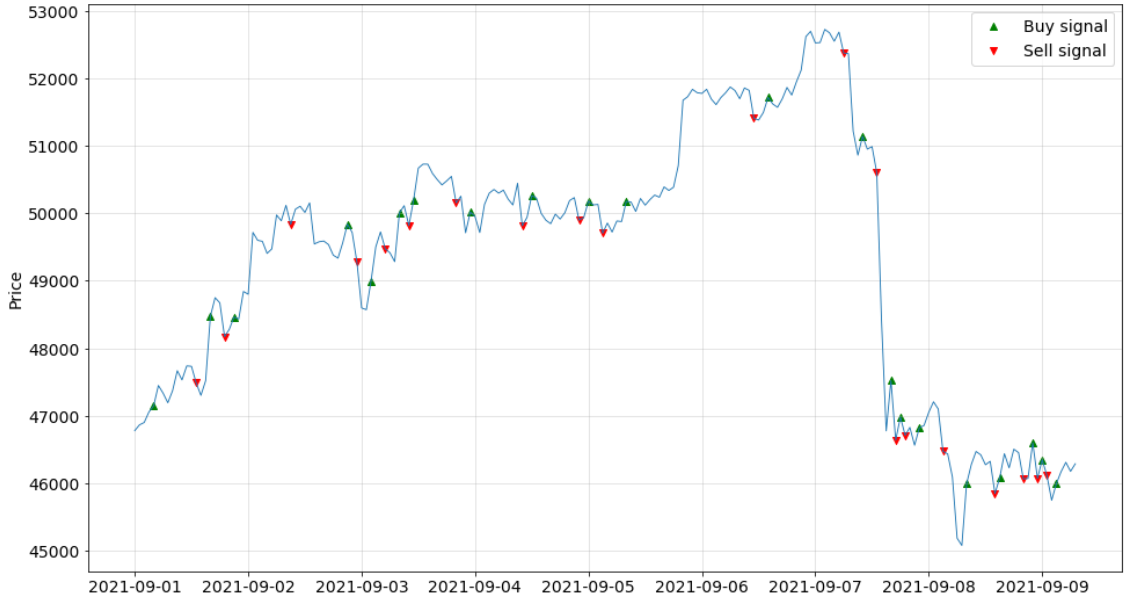
Results

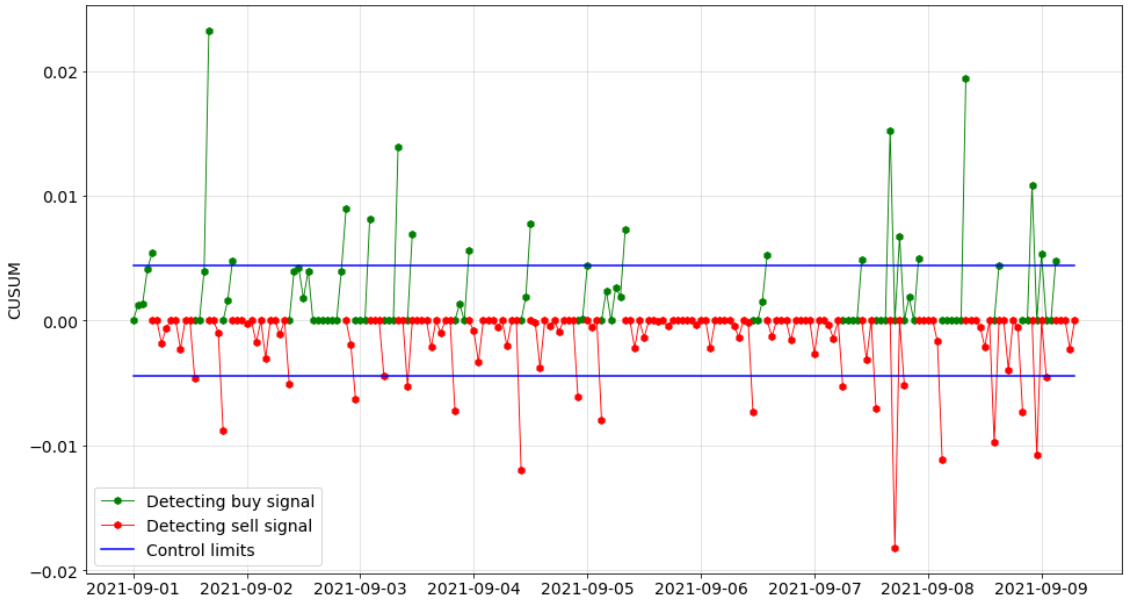
1-a-i. CUSUM Method Based on Return feature Montgomery model Without Transaction fees





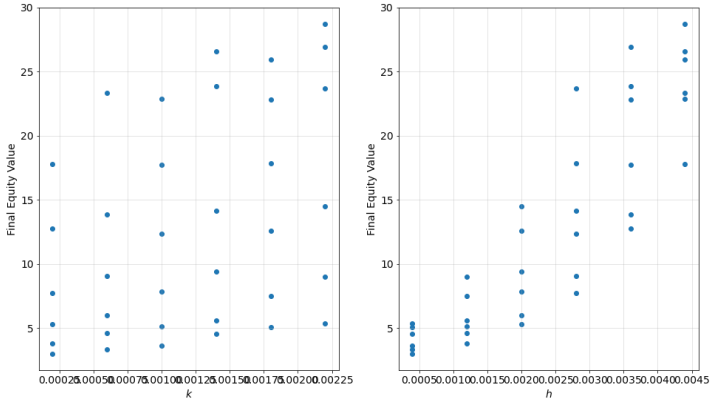
k	h	finalEquity
0.0006	0.0044	125.070786
0.0022	0.0028	123.893409
0.0014	0.0036	123.366604
0.0014	0.0044	115.942143
0.0002	0.0044	114.155806



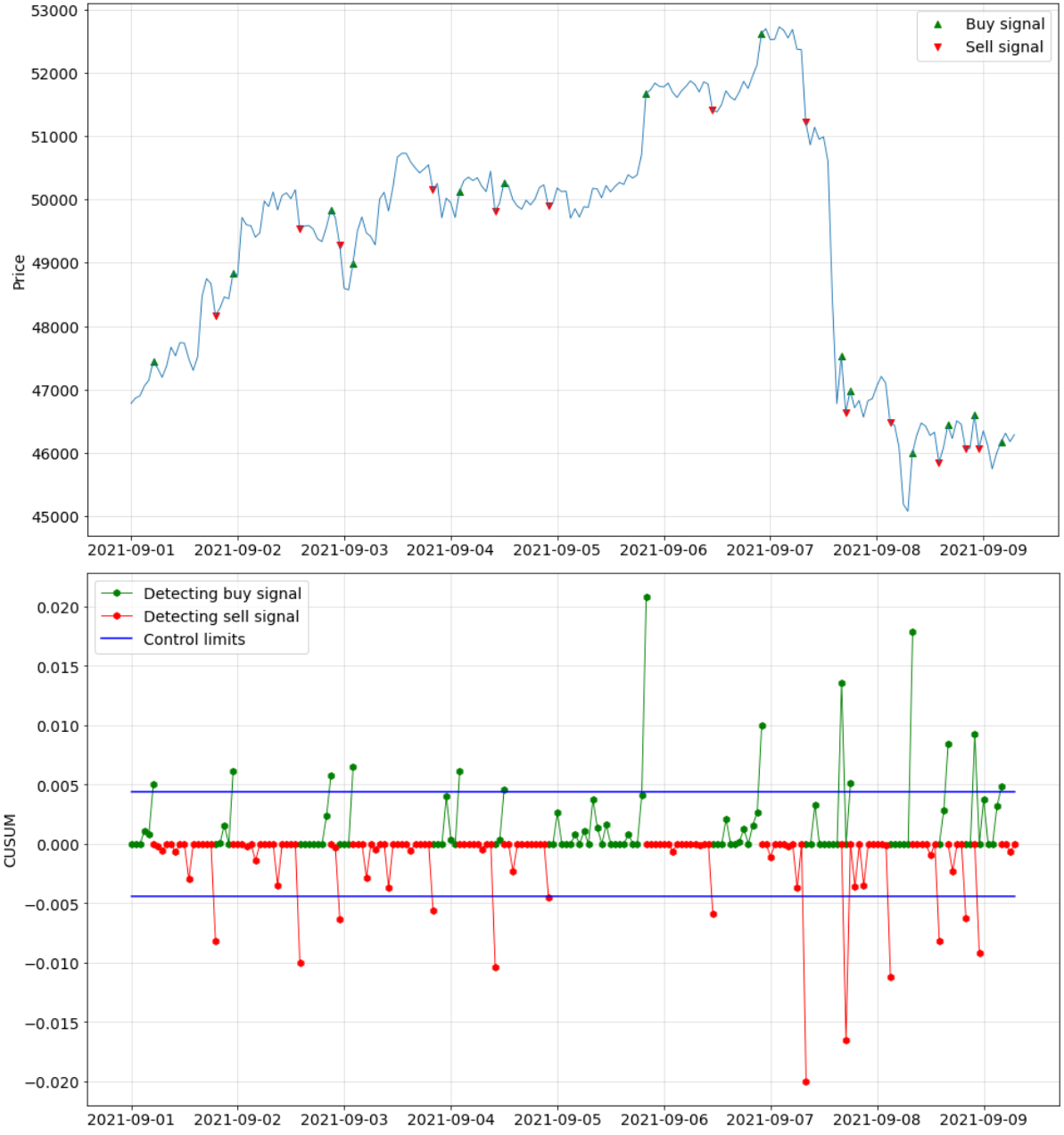


1-a-i. CUSUM Method Based on Return feature Montgomery model With Transaction fees

Transaction Fee = %0.5

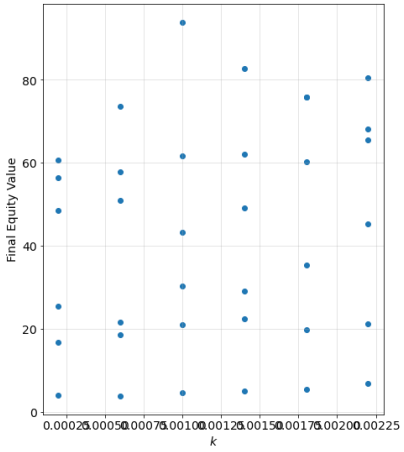


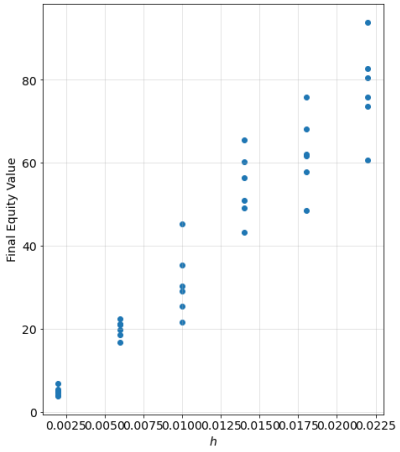
k	h	finalEquity
0.0022	0.0044	28.717913
0.0022	0.0036	26.897201
0.0014	0.0044	26.559938
0.0018	0.0044	25.919781
0.0014	0.0036	23.832417

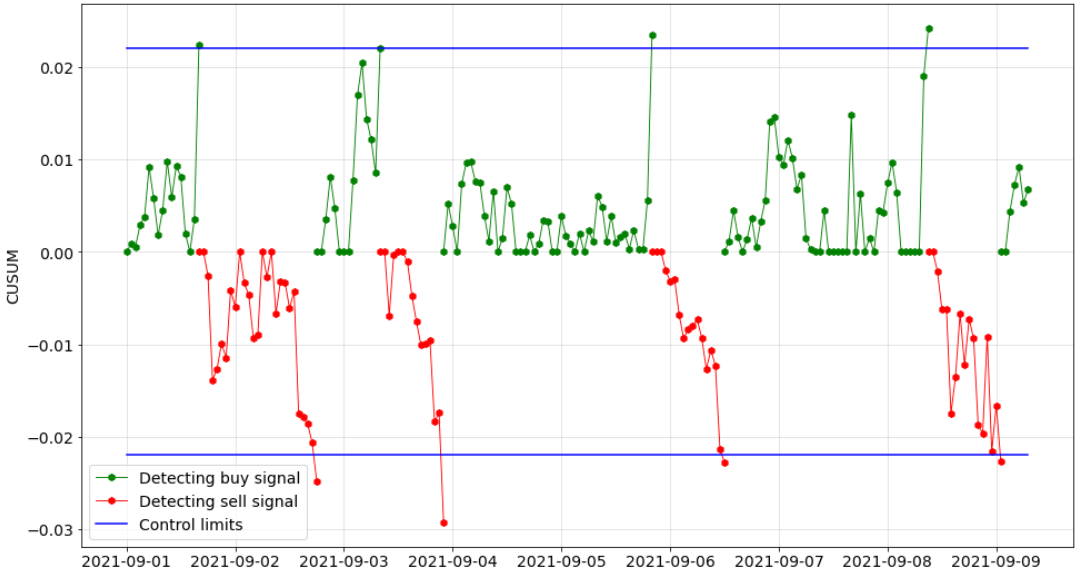


Results

1-a-ii. CUSUM Method Based on Return feature Literature model



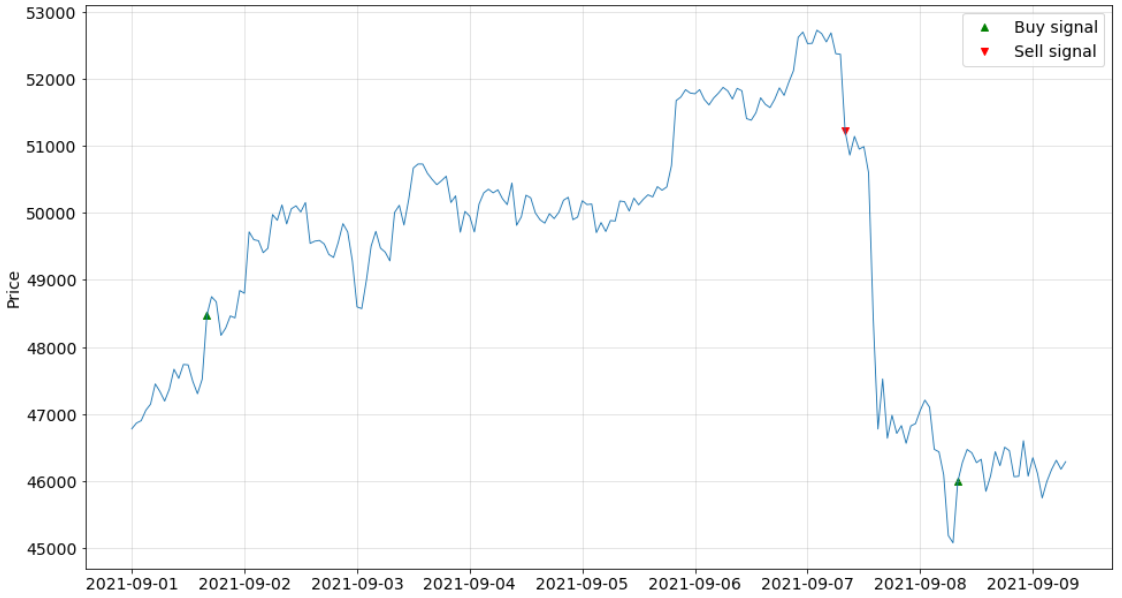


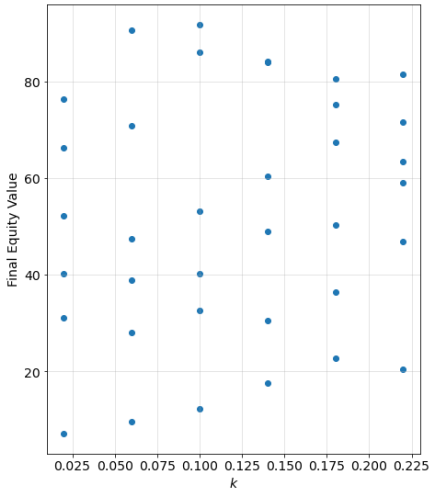


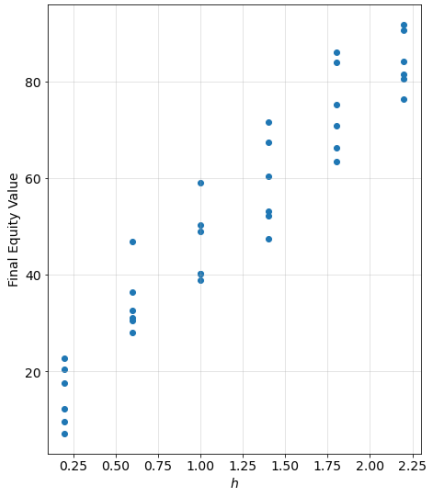
Results

1-b-i. CUSUM Method Based on Residuals feature (Residual Based CUSUM) Montgomery model

k	h	finalEquity
0.10	2.2	91.771336
0.06	2.2	90.646002
0.10	1.8	86.014025
0.14	2.2	84.202405
0.14	1.8	83.983150

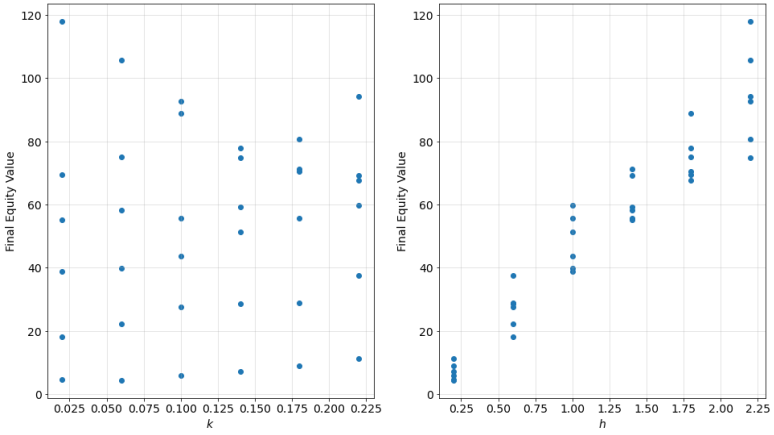




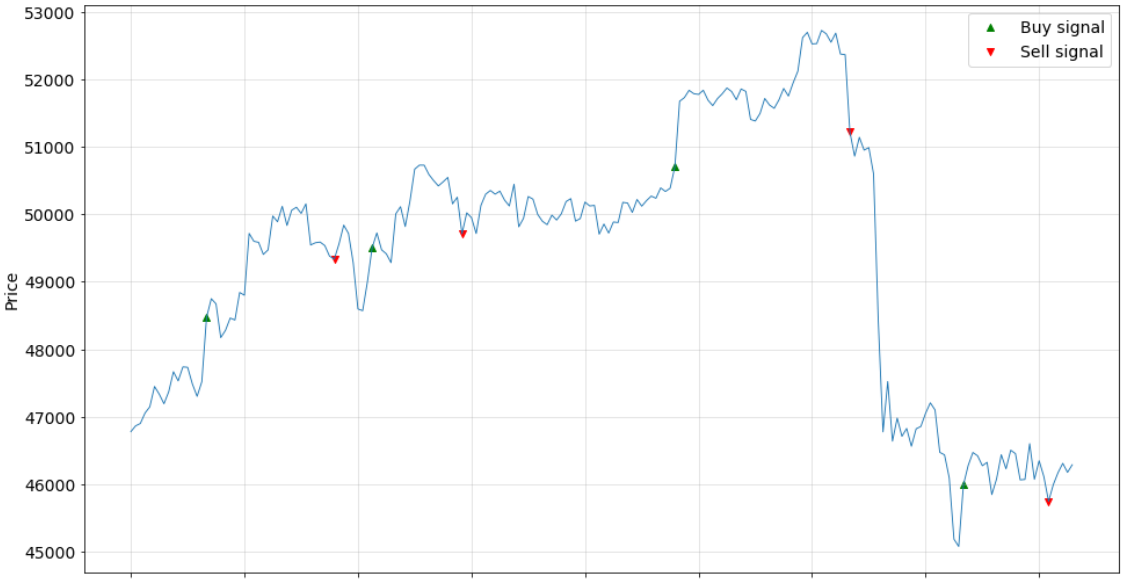


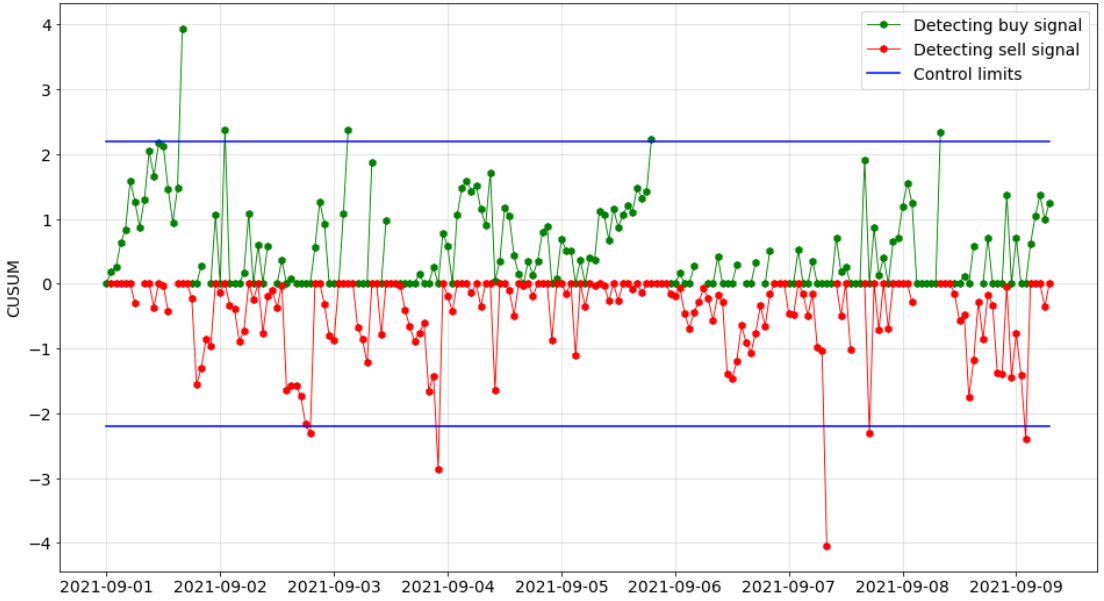
Results

1-b-ii. CUSUM Method Based on Residuals feature (Residual Based CUSUM) Literature model



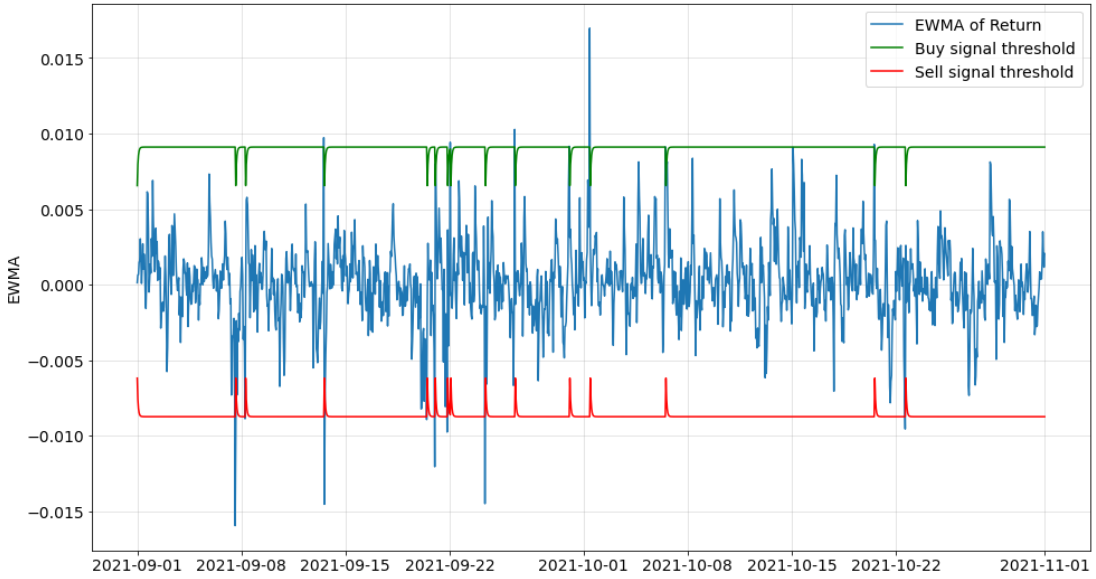
	k	h	finalEquity
5	0.02	2.2	160.145176
11	0.06	2.2	142.707081
16	0.10	1.8	128.593077
17	0.10	2.2	125.941407
35	0.22	2.2	119.150920





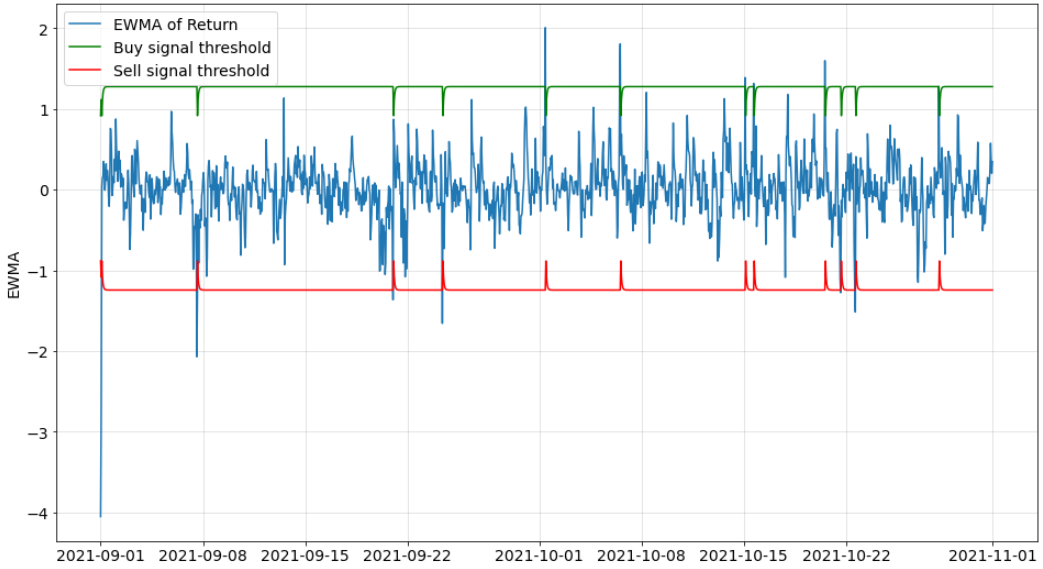
Results

2.a) EWMA Method Based on Return feature



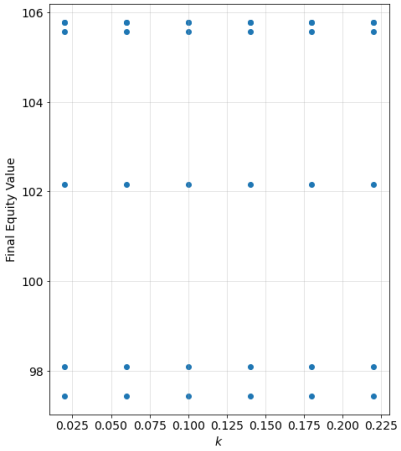
Results

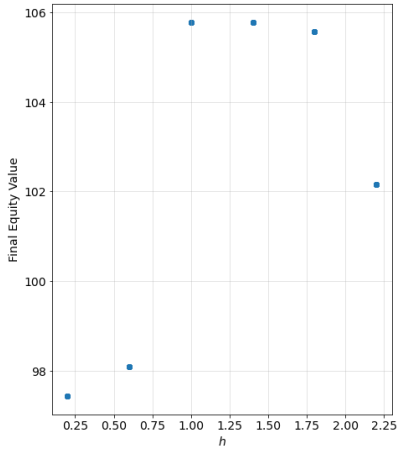
2.b) EWMA Method Based on Residuals feature (Residual based EWMA)



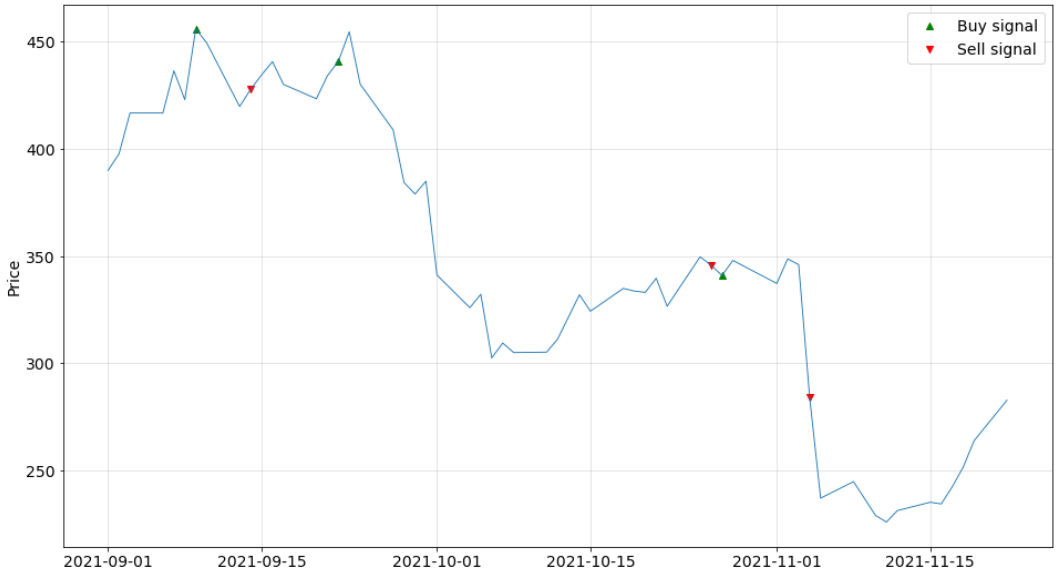
Results

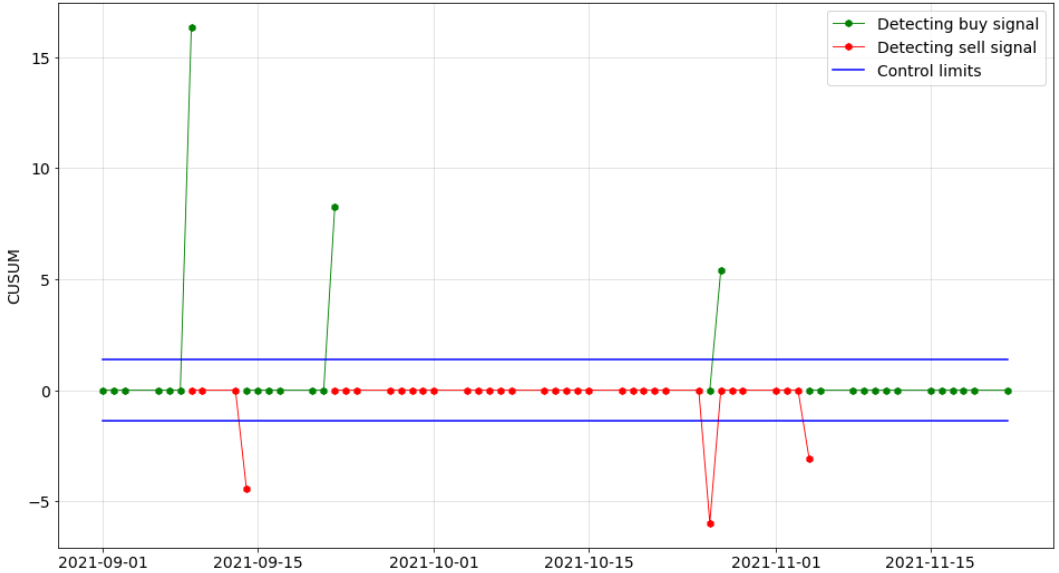
3. Risk adjusted CUSUM Stock Market Data





k	h	finalEquity
0.10	1.4	105.779527
0.06	1.0	105.779527
0.10	1.0	105.779527
0.22	1.0	105.779527
0.22	1.4	105.779527





Results

4. Back test:

Ratio Table (ARL):

- Average Exposure Time: ARL for sell signal
- Average Waiting Time: ARL for buy signal
- Sharpe Ratio: Risk adjusted return (Extra return on holding a risky asset)
- Sortino Ratio: Downside risk adjusted return (Better indicator)

	Strategy	Start Time	End Time	Duration	Exposure Time	Waiting Time	Sharpe Ratio	Sortino Ratio
0	Return CUSUM (No Fee)	2021-09-01	2021-11-01	61 days	0 days 07:05:46.666666666	0 days 03:37:46.666666666	0.005723	0.009358
1	Return CUSUM	2021-09-01	2021-11-01	61 days	0 days 11:11:33.975903614	0 days 06:15:10.843373493	-0.042338	-0.069245
2	Residual CUSUM	2021-09-01	2021-11-01	61 days	4 days 09:54:32.727272727	0 days 20:05:27.272727272	0.032587	0.053463
3	Return CUSUM (Yi et al. 2006)	2021-09-01	2021-11-01	61 days	0 days 17:52:00	1 days 05:26:00	0.000115	0.000180
4	Residual CUSUM (Yi et al. 2006)	2021-09-01	2021-11-01	61 days	0 days 17:20:27.272727272	0 days 15:28:38.181818181	-0.028782	-0.044776
5	Residual EWMA	2021-09-01	2021-11-01	61 days	30 days 14:00:00	NaT	-0.007603	-0.009654
6	Buy and Hold	2021-09-01	2021-11-01	61 days	61 days 00:00:00	NaT	0.026543	0.043066

Results

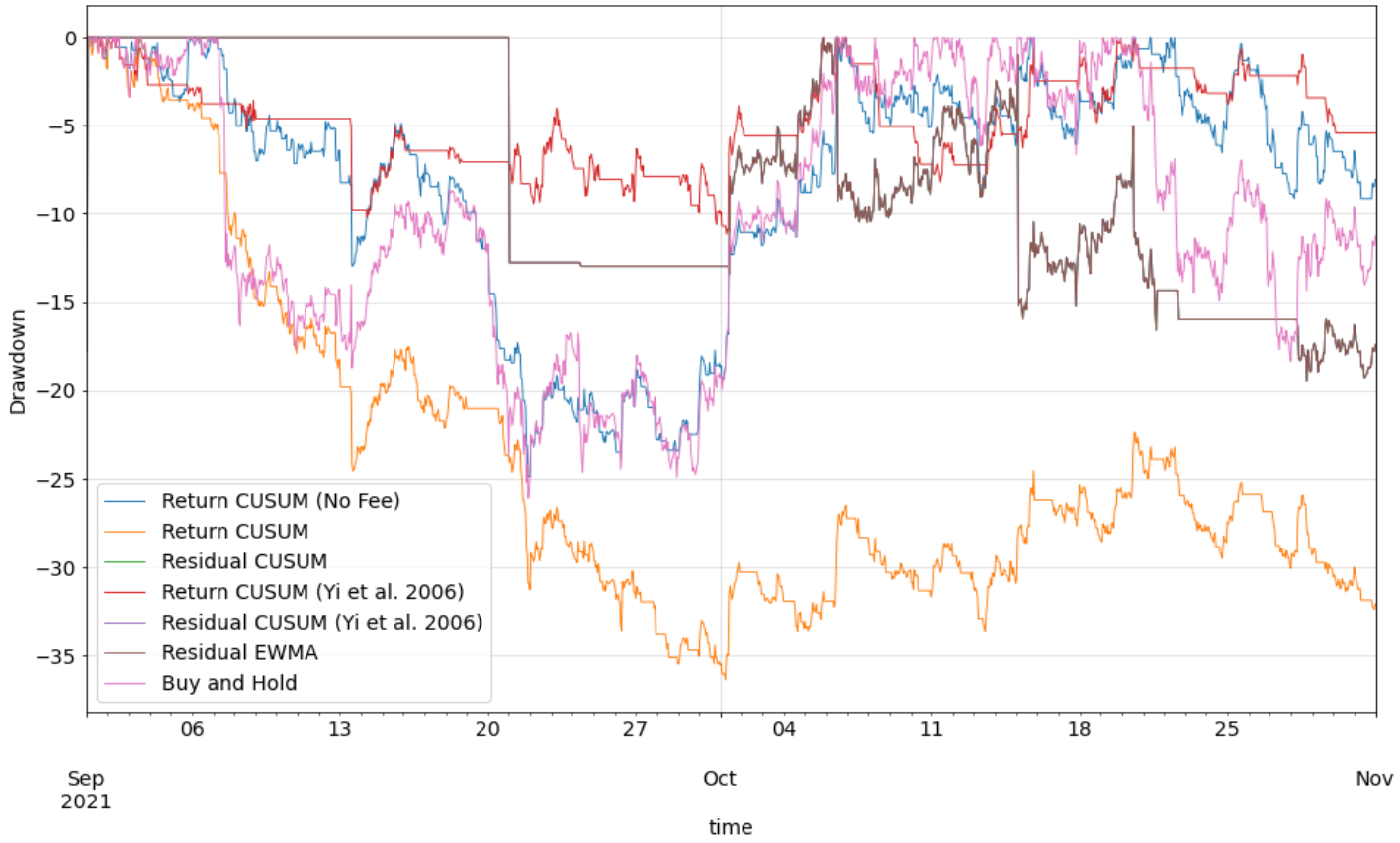
4. Back test:

Equity Plot:

Results

4. Back test:

Drawdown plot:



➔ Return CUSUM (No Fee) and Return CUSUM (Yi et al. 2006) has better performance for risk-avoiders.

Findings

1. Main Conclusion:

a) Control chart-based strategies can be profitable, and significantly reduce the risk while holding the asset.

b) Residual-based CUSUM outperformed the benchmark in excess return.

2. Strength and Shortage of applied method:

a) We developed a fully automated API to test for best control chart based trading strategy for given coin.

b) Our results outperformed benchmark in key risk factors.

c) First time applied these methods to cryptocurrency market.

d) Innovative way of applying risk-adjusted chart for industry trend.

e) h is symmetric in our study. In real market, asymmetric limits may be used.

f) Transaction cost structure is oversimplified in our model.

Findings

3. Applicational insights:

Do transaction fees always lead to loss? No.

CUSUM can still work by increasing k, h, which means reducing trading frequency and making profit.

insights: transaction fee affects a lot! In reality, transaction fee is much more complicated than a fixed rate. Future work can apply more complex transaction and management fee structure in order to achieve a better strategy using control charts.

4. Recommendations for future work:

Generalization of k and h for a single method and different coins.

Search for better lambda for EWMA strategies.

Integrate more complex transaction cost considerations.

Test in emerging markets and other markets for broader application.

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