



Encoder Decoder LSTM

구현 및 실험 결과 보고

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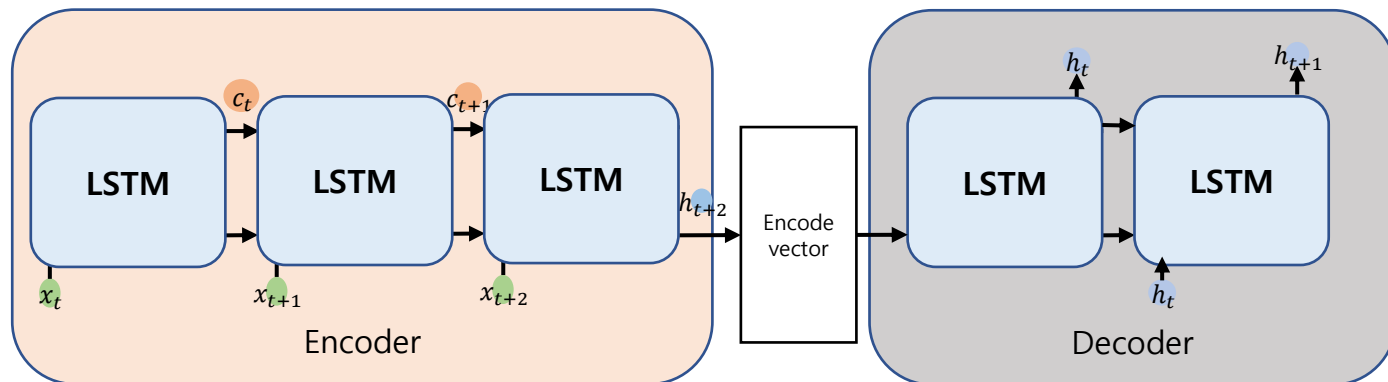
Introduction

- 기존의 LSTM등 RNNs의 모형에서 input length와 output length가 다른 데이터를 다룰 수 없는 문제점이 있음.
- 이를 해결하기 위해 Encoder-Decoder 구조를 LSTM에 적용함.
- input length와 output length가 다른 길이가 되어도 출력이 가능하게 됨.

Related works

- Encoder-Decoder LSTM

- 두개의 LSTM 아키텍처가 결합된 구조.



- Encoder아키텍처에서 셀의 마지막 시점의 hidden state를 Decoder로 넘겨줌
- 받은 hidden state를 Decoder에서 최초의 hidden state로 사용함.

Related works

- Stock data Normalization

학회 명	논문 명	발간 년도	인용 수	normalization 방식	normalization 범위	실제 내용
Expert Systems With Applications	ModAugNet: A new forecasting framework for stock market index value with an overfitting prevention LSTM module and a prediction LSTM module	2018	80	min-max normalization	언급 x	where X is original value at a data point, X max and X min are maximum and minimum value of a specific feature, respectively. Consequently, every feature change could be captured in the range of [0,1].
Expert Systems with Applications	Stock price prediction using deep learning and frequency decomposition	2020	1	min-max normalization	언급 x	After decomposition of indices into various frequency spectra, it is required to convert the original data to normal data before training. Normalization leads to the adjustment of the data noise effect and implementation of neural networks with high efficiency and speed (Makridakis, 1993; Diehl, et al., 2015). To this end, we use the following equation.
IEEE ACCESS	Multivariate Financial Time-Series Prediction With Certified Robustness	2020	2	min-max normalization	언급 x	To detect the agricultural commodity futures price pattern, it is necessary to normalize the agricultural commodity futures price data. Since the LSTM neural network requires the agricultural commodity futures patterns during training, we use the "min-max" normalization method to reform dataset, which keeps the pattern of the data, as follows:
Quantitative Bio-Science	Forecasting the KOSPI 200 Stock Index Based on LSTM Autoencoder	2020	0	batch normalization	언급 x	batch normalization was added to the model, and early stopping in Keras's callback functions was utilized. For the loss function and the optimization function, both the autoencoder and the predictive model used MSE (Mean-Squared-Error) and Adam Optimizer.
International Journal of Machine Learning and Cybernetics	Study on the prediction of stock price based on the associated network model of LSTM	2020	20	min-max normalization	언급 x	Due to the different measurement unit of different stock index data, for avoiding the impact of different measurement unit, all the attribute data are normalized to fall within a same range. In this paper, the min-max normalization method is used. The normalization function is shown in Eq. 11

Proposed method

- Stock data Normalization

학회 명	논문 명	발간 년도	인용 수	normalization 방식	normalization 범위	실제 내용
IEEE ACCESS	Feature Engineering for Mid-Price Prediction With Deep Learning	2019	18	min-max normalization	전체 데이터에 적용	The next step of the pre-processing step is data normalization. We perform a filtering and a normalization method during the feature extraction process and training. The first one is a statistical filtering method , while the second one is based on MinMax . More specifically, we perform the filtering methodology first and apply it directly on the raw MB data. The main idea of the methodology is to identify and eliminate any observation that does not reflect market activity.
Neural Computing and Applications	Stock price prediction based on deep neural networks	2019	43	min-max normalization	언급 x	To facilitate better observation and comparison of the experimental results, PSR, de-noising and normalization were first performed in the model parameter experiment.
Proceedings of Machine Learning Research	Stock Price Prediction Using Attention-based Multi-Input LSTM	2018	33	min-max normalization	언급 x	Notice that the MSE we calculated are derived from normalized data. That's because there exists huge value gap among different stocks. If we use original stock price to evaluate error, the error of high price stocks would probably be much more larger than low price ones, which implies models perform better on high price stocks would very likely to have better overall performance. Thus the performance on low price stocks would become dispensable. To avoid the bias caused by the aforementioned problem we evaluate the error with normalized stock price ranged from -1 to 1.
IEEE	Hybrid Deep Learning Model for Stock Price Prediction	2018	18	min-max normalization	전체 데이터에 적용	we present the normalized training data form 1950 to 2002. The curve shows the randomness of stock price data. Our main goal is to predict the closing price of next day. We put all the training data into a one dimensional vector and pass it to the network with a fixed learning rate(.001). Figure 6 shows the normalized test dataset representation, which is also showing the randomness of stock price.

Proposed method

- Stock data Normalization

학회 명	논문 명	발간 년도	인용 수	normalization 방식	normalization 범위	실제 내용
Physica A: Statistical Mechanics and its Applications	Financial time series forecasting model based on CEEMDAN and LSTM	2018	111	min-max normalization	전체 데이터에 적용	Where minx(t) and maxx(t) are the minimum and maximum value of the whole time series respectively.
International Conference on Advances in Computing, Communication Systems and Informatics (ICA CCI)	STOCK PRICE PREDICTION USING LSTM,RNN AND CNN-SLIDING WINDOW MODEL	2017	235	min-max normalization	언급 x	The data varies with in a range of 2000 to 4000 for Infosys and TCS and for Cipla it is 400 to 700. To unify the data range, it was subjected to normalization and was mapped to a range of 0 to 1. This normalized data was given to the network for training.
IEEE International Conference On Recent Trends in Electronics Information & Communication Technology (RTEICT)	Short Term Stock Price Prediction Using Deep Learning	2017	41	min-max normalization	언급 x	The data of each stock consists of approximately 85000 - 90000 points. The data was normalized into the range of [0, 1] using MinMaxScaler(2), since neural networks are known to be sensitive to unnormalized data, which is then fed to the prediction model.
IEEE International Conference on Big Data	A LSTM-based method for stock returns prediction : A case study of China stock market	2015	286	mean and standard deviation	각각의 sequence vector에 적용	normalization was applied for each vector of a sequence by using the mean and standard deviation of each stock computed from the training set.
International Conference on Business Analytics and Intelligence	Stock Price Prediction Using Machine Learning and Deep Learning Frameworks	2018	19	min-max normalization	전체 데이터에 적용	The raw data is normalized using the min-max normalization
Expert Systems With Applications	ModAugNet: A new forecasting framework for stock market index value with an overfitting prevention LSTM module and a prediction LSTM module	2018	80	min-max normalization	전체 데이터에 적용	X max and X min are maximum and minimum value of a specific feature,

Experimental setting

- Dataset

stocks	N	Train	val	test
KOSPI	5156	3210	979	967
KOSDAQ(2013-03-03 ~)	1898	938	474	486
NASDAQ	5265	3263	1002	1000
S&P 500	5265	3263	1002	1000
다우존스	5265	3263	1002	1000
홍콩 항셱	5151	3196	976	979
일본 니케이	5124	3182	971	971
독일 DAX	5306	3300	1005	1001
프랑스 CAC	5343	3313	1015	1015
스페인 IBEX	5314	3283	1017	1014
대만 기권	5144	3206	971	967
네덜란드 AEX	5347	3316	1016	1015
인도 섀섹스	5151	3204	970	977
브라질 보베스파	5265	3263	1002	1000
Gold price	5050	3067	994	989
Oil price(2000-08-23 ~)	5060	3076	994	990
10년 만기 미국 국채	3264	3264	1027	688
10년 만기 한국 국채				
비트코인 암호화폐(2014-09-17 ~)	2275	1560	359	356
이더리움 암호화폐(2015-08-07 ~)	1951	1236	359	356

KOSPI INDEX log difference

2000.01.01 – 2020.12.31

Experimental setting

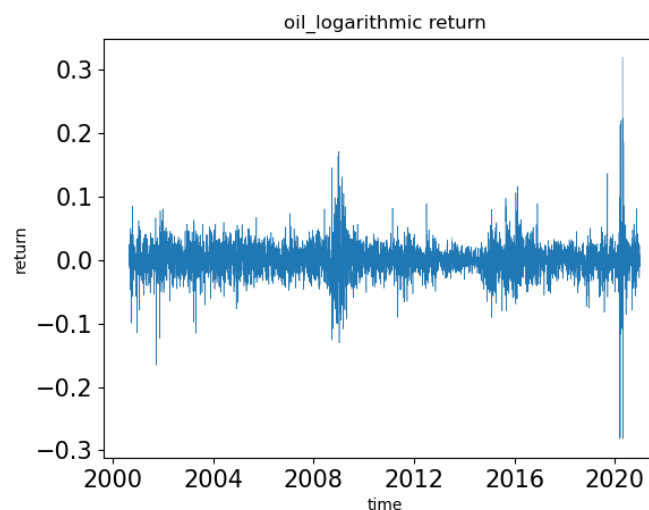
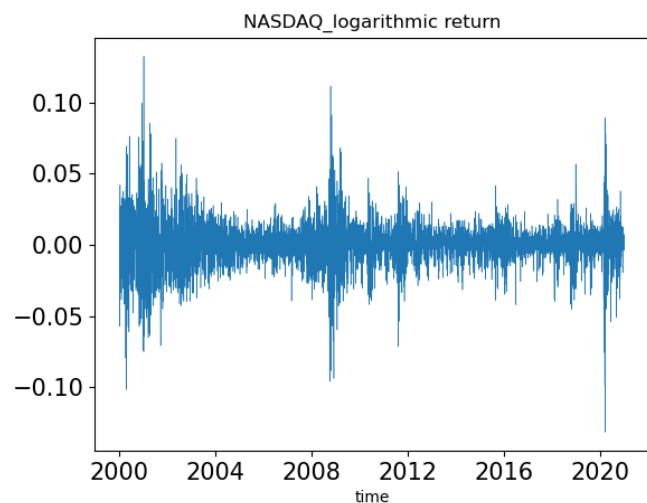
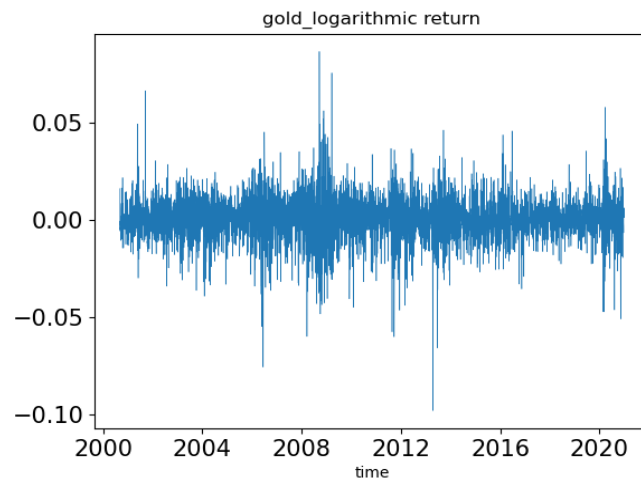
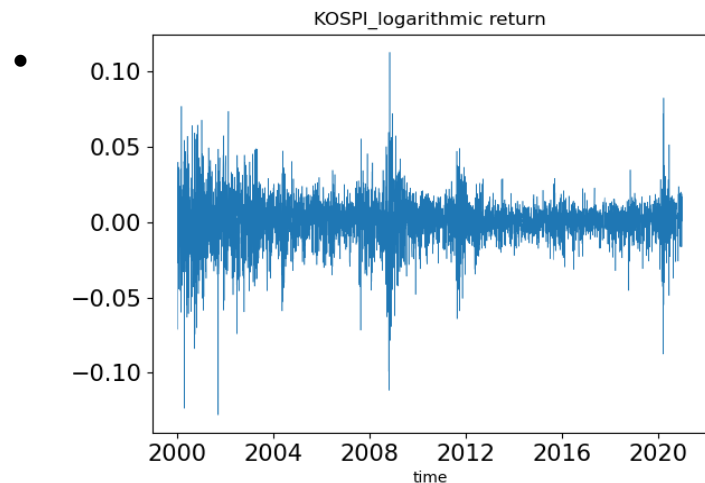
- Statistics

stocks	Mean	Standard deviation	Skewness	Kurtosis(3)	Jerque Bera	ADF
KOSPI	1582.518	587.343	-0.421	1.861	432.61***	-0.438834
KOSDAQ	668.623	103.98	0.46	2.632	78.4663***	-1.173884
NASDAQ	3791.769	2367.556	1.388	4.395	2125.9183***	3.346301
S&P 500	1653.635	674.270	1.033	3.067	941.5057***	1.678640
다우존스	14655.366	5792.134	1.043	2.906	959.6158***	0.870942
홍콩恒生	19919.806	5726.487	-0.18	2.076	211.8634***	-1.579436
일본 니케이	14640.566	4694.21	0.393	2.009	342.692***	-0.491717
독일 DAX	7661.465	3006.491	0.385	1.978	363.2483***	-0.506127
프랑스 CAC	4469.135	918.824	0.153	2.207	161.6942***	-2.233112
스페인 IBEX	9680.838	2017.084	0.667	3.565	466.6305***	-2.262163
대만 기권	7903.82	2055.782	0.243	2.707	69.2831***	-0.264858
네덜란드 AEX	435.655	108.924	0.265	2.222	197.9852***	-1.899507
인도 섹스	17921.698	11385.273	0.401	2.120	305.4783***	0.679944
브라질 보베스파	3791.769	2367.556	1.388	4.395	2125.9183***	3.346301
Gold price	997.637	479.258	-0.105	1.796	315.6375***	-0.459757
Oil price	61.785	25.912	0.400	2.381	216.5233***	-1.997886
10년 만기 미국 국채	118.257	9.575	-0.285	2.145	219.8195***	-2.216594
10년 만기 한국 국채						
비트코인 암호화폐	4925.441	4830.747	1.056	4.332	595.9625***	1.440318
이더리움 암호화폐	223.111	231.702	1.601	6.123	1642.5896***	-2.082944
KOSPI INDEX log difference	0.000193	0.0149	-0.572	10.03	10943.0983***	-33.339841***

Used Close(종가) variable.

Experimental setting

- logarithmic return : $\ln((t+1)/t)$ t : 시점이 t 일때 종가(close)



- logarithmic return
 - 수익률을 나타내는 지표 중의 하나.
 - 일반 수익률보다 실제 수익률에 더 가까운 지표.

Experimental setting

- Data normalization
 - min-max normalization
- Loss function
 - Used MSE Loss as loss function
- Optimizer
 - Adam
- Metric
 - $\text{MAE}(e^{\text{predicted value}}, e^{\text{true value}})$
 - $\text{RMSE}(e^{\text{predicted value}}, e^{\text{true value}})$
 - $\text{MAPE}(e^{\text{predicted value}}, e^{\text{true value}})$

Hyperparameters	Number
hidden state, cell state dimension	10
input sequence length	20
output sequence length	1
epoch	120
Batch size	128

Experimental setting

- To determine the detailed performance of a model
- Add another model evaluation metric.

- Mean Absolute Percentage Error (MAPE) = $\frac{\sum_{t=1}^n \left| \frac{y_t - \hat{y}_t}{y_t} \right|}{n} \cdot 100(\%)$
 - MAPE is undefined for data points where the value is zero.
 - MAPE is biased towards prediction that are systemically less than the actual values themselves

$$y = 20, \hat{y} = 10, n = 1 \rightarrow MAPE = 50\%$$

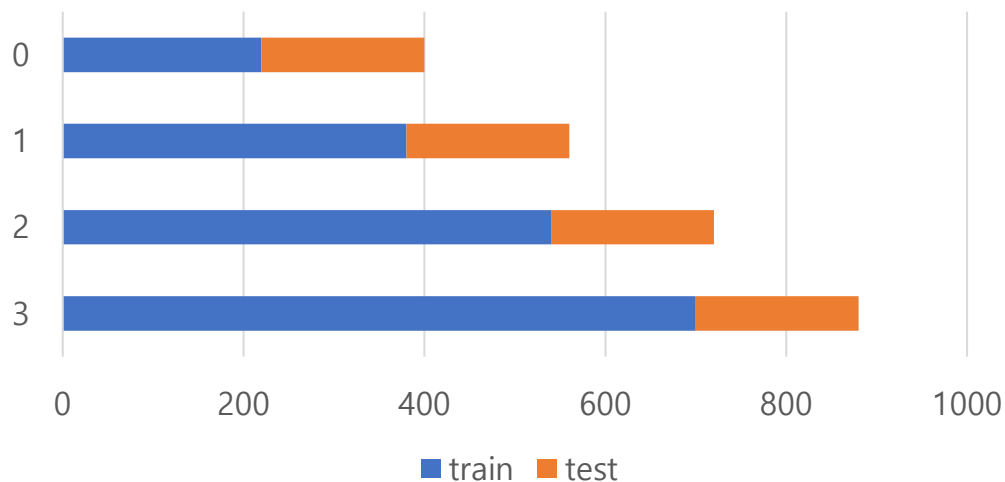
$$y = 10, \hat{y} = 20, n = 1 \rightarrow MAPE = 100\%$$

- Compare three metrics.
 - MAE
 - RMSE
 - MAPE

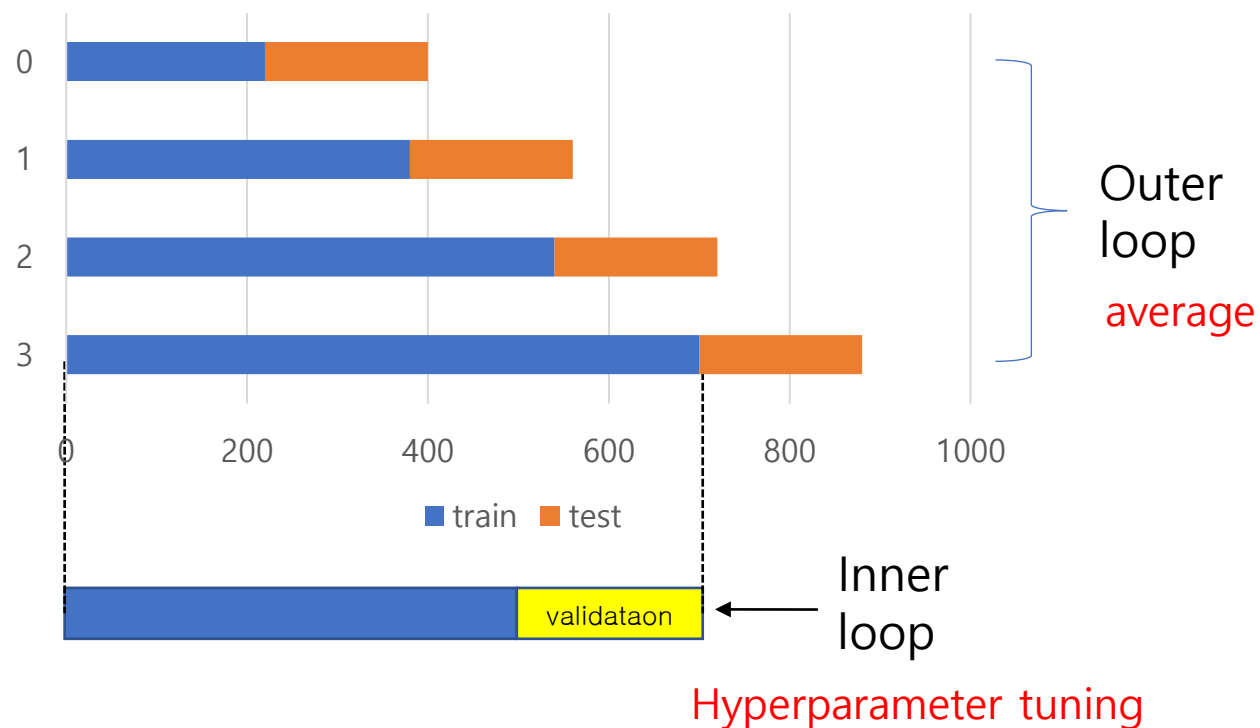
Experimental setting

- Stock dataset split in timeseries data

Expanding window Cross Validation



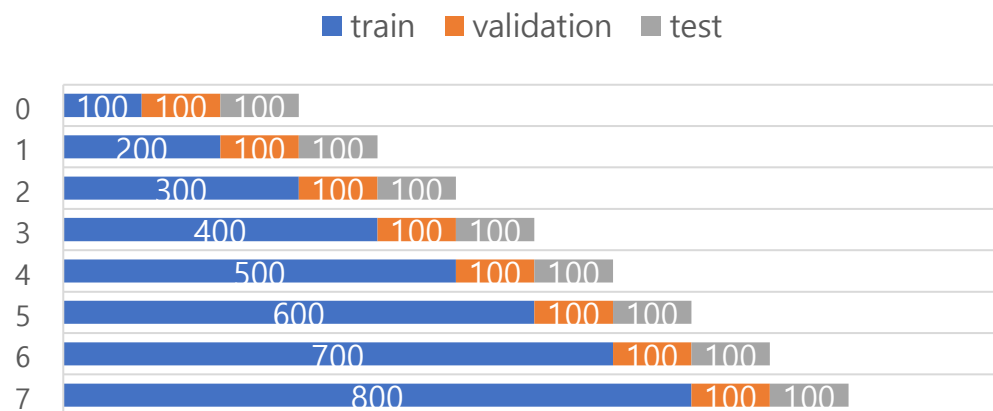
Nasted time series Cross Validation



Experimental setting

- Nested time series Cross Validation

NESTED TIME SERIES CROSS VALIDATION



Train : validation : test = 8 : 1 : 1

- Maximum iteration is 8
- Iteration from 3 to 5 is used universally in timeseries data cross-validation.

- More data should be collected.

Experimental setting

- Investment strategie

Problem determining INPUT length

- **Value** (가치투자)
- **Asset allocation** (자산배분 전략) – Low correlation, Percentage of assets
- **Quality** (우량주 투자)
- **Momentum** (모멘텀 전략)
- **Scalping** - futures contract

- Hyperparameter tuning

Experimental setting

- Investment strategie

- normalization applied to **each split sequence**

- “normalization was applied for each vector of a sequence by using”, A LSTM-based method for stock returns prediction : A case study of China stock market (2015)

- normalization applied to **entire sequence**

- “The raw data is normalized using the min-max normalization”, Stock Price Prediction Using Machine Learning and Deep Learning Frameworks

>> Both of the strategies can be selected

Comparison results

- Mean Absolute Error (Normalized to each sequence)

Data	Proposed	Standard Deviation	RNN	Standard Deviation	LSTM	Standard Deviation	GRU	Standard Deviation	Enc-Dec LSTM	Standard Deviation
네덜란드 AEX(^AEX)			9.700	4.321	9.072	2.430	12.169	5.305		
인도 섹스(^BSESN)			522.481	143.644	757.710	311.438	635.134	240.285		
브라질 보베스파(^BVSP)			1531.036	549.161	1529.299	754.228	2040.192	650.570		
다우존스(^DJI)			379.666	155.520	386.981	130.981	383.127	141.125		
프랑스 CAC(^FCHI)			132.848	64.138	114.632	47.652	86.384	43.260		
독일 DAX(^GDAXI)			287.096	174.637	236.222	97.034	276.421	131.694		
S&P 500(^GSPC)			45.127	28.311	40.281	20.761	33.122	14.978		
홍콩 항셱(^HSI)			625.978	235.568	464.189	119.809	592.841	292.263		
스페인 IBEX(^IBEX)			223.378	159.649	222.907	108.678	245.819	167.813		
NASDAQ(^IXIC)			109.496	46.546	122.264	41.803	126.881	49.249		
KOSDAQ(^KQ11)			27.665	9.407	25.220	14.498	23.798	11.050		
KOSPI(^KS11)			35.608	13.477	39.714	13.813	31.784	11.158		
일본 니케이(^N225)			537.349	282.333	482.213	198.073	539.397	336.067		
대만 기권(^TWII)			159.542	66.302	172.253	62.575	157.141	58.127		
비트코인 암호화폐(BTC-USD)			419.973	274.202	325.423	249.265	542.294	699.560		
Oil price(CL=F)			2.953	1.809	1.990	0.913	2.678	2.093		
이더리움 암호화폐(ETH-USD)			40.476	33.185	28.455	21.580	27.205	21.683		
Gold price(GC=F)			21.052	12.822	20.112	14.340	22.077	14.279		
10년 만기 미국 국채										
10년 만기 한국 국채										

Comparison results

- Root Mean Squared Error (Normalized to each sequence)

Data	Proposed	Standard Deviation	RNN	Standard Deviation	LSTM	Standard Deviation	GRU	Standard Deviation	Enc-Dec LSTM	Standard Deviation
네덜란드 AEX(^AEX)			11.304	5.039	10.566	3.010	14.227	6.222		
인도 섹스(^BSESN)			625.698	182.463	869.819	402.124	727.703	268.761		
브라질 보베스파(^BVSP)			1858.968	676.142	1829.228	913.358	2366.848	728.495		
다우존스(^DJI)			451.991	207.007	447.909	167.888	449.206	177.294		
프랑스 CAC(^FCHI)			154.815	76.128	132.486	56.154	102.502	47.582		
독일 DAX(^GDAXI)			339.719	193.275	274.045	103.857	319.372	161.814		
S&P 500(^GSPC)			52.531	35.028	47.002	25.976	39.627	19.338		
홍콩 항셱(^HSI)			751.627	282.089	540.112	120.722	687.794	313.541		
스페인 IBEX(^IBEX)			262.575	175.966	256.591	116.325	278.552	174.035		
NASDAQ(^IXIC)			127.552	57.086	144.600	50.219	147.346	57.546		
KOSDAQ(^KQ11)			31.153	9.875	29.395	16.572	27.159	11.997		
KOSPI(^KS11)			41.436	14.432	44.939	14.383	37.307	13.317		
일본 니케이(^N225)			610.658	288.148	550.857	213.837	614.475	368.112		
대만 기권(^TWII)			183.530	70.931	197.271	68.478	179.187	59.845		
비트코인 암호화폐(BTC-USD)			536.844	363.039	427.415	327.390	666.699	817.629		
Oil price(CL=F)			3.894	2.953	2.794	2.216	3.594	3.203		
이더리움 암호화폐(ETH-USD)			50.980	44.595	36.175	26.770	34.514	27.134		
Gold price(GC=F)			26.200	16.438	25.728	17.718	28.299	18.431		
10년 만기 미국 국채										
10년 만기 한국 국채										

Comparison results

- Mean Absolute Percentage Error (Normalized to each sequence)

Data	Proposed	Standard Deviation	RNN	Standard Deviation	LSTM	Standard Deviation	GRU	Standard Deviation	Enc-Dec LSTM	Standard Deviation
네덜란드 AEX(^AEX)			0.02149	0.01151	0.01938	0.00575	0.02651	0.01254		
인도 섹스(^BSESN)			0.01874	0.00637	0.02700	0.01201	0.02263	0.00982		
브라질 보베스파(^BVSP)			0.02367	0.00858	0.02444	0.01348	0.03200	0.01248		
다우존스(^DJI)			0.01884	0.00642	0.01926	0.00540	0.01879	0.00609		
프랑스 CAC(^FCHI)			0.02920	0.01604	0.02491	0.01165	0.01842	0.00936		
독일 DAX(^GDAXI)			0.02807	0.01809	0.02219	0.00922	0.02619	0.01290		
S&P 500(^GSPC)			0.01934	0.01087	0.01704	0.00705	0.01425	0.00514		
홍콩 항셱(^HSI)			0.02536	0.01034	0.01907	0.00639	0.02369	0.01168		
스페인 IBEX(^IBEX)			0.02469	0.01909	0.02437	0.01341	0.02631	0.01815		
NASDAQ(^IXIC)			0.01863	0.00593	0.02108	0.00644	0.02229	0.00838		
KOSDAQ(^KQ11)			0.03983	0.01357	0.03586	0.02034	0.03414	0.01655		
KOSPI(^KS11)			0.01690	0.00552	0.01907	0.00631	0.01553	0.00614		
일본 니케이(^N225)			0.03159	0.02126	0.02795	0.01461	0.03230	0.02505		
대만 기권(^TWII)			0.01696	0.00828	0.01824	0.00751	0.01643	0.00649		
비트코인 암호화폐(BTC-USD)			0.07405	0.03593	0.05769	0.02862	0.08609	0.07321		
Oil price(CL=F)			0.07050	0.08610	0.04872	0.05775	0.06203	0.07696		
이더리움 암호화폐(ETH-USD)			0.14305	0.09475	0.10787	0.09124	0.11357	0.07691		
Gold price(GC=F)			0.01556	0.00919	0.01484	0.01028	0.01643	0.01052		
10년 만기 미국 국채										
10년 만기 한국 국채										

Comparison results

- Mean Absolute Error (Normalized to entire sequence)

Data	Proposed	Standard Deviation	RNN	Standard Deviation	LSTM	Standard Deviation	GRU	Standard Deviation	Enc-Dec LSTM	Standard Deviation
네덜란드 AEX(^AEX)			33.674	14.620	55.825	50.071	115.306	98.118		
인도 섹섹스(^BSESN)			3176.914	2146.348	2568.407	1459.980	4821.795	3969.823		
브라질 보베스파(^BVSP)			15418.960	5297.980	17312.190	19089.080	7118.685	6618.295		
다우존스(^DJI)			2543.574	1488.713	3742.200	2446.551	3769.545	3016.697		
프랑스 CAC(^FCHI)			802.309	518.714	794.732	526.028	611.469	430.844		
독일 DAX(^GDAXI)			1827.681	1309.307	2956.458	2815.040	2599.160	1913.381		
S&P 500(^GSPC)			459.890	520.741	391.832	353.848	431.442	421.826		
홍콩 항셱(^HSI)			3738.814	4563.416	2977.772	1654.907	3686.715	2670.592		
스페인 IBEX(^IBEX)			2312.172	2097.362	2620.912	2544.095	2354.442	1270.599		
NASDAQ(^IXIC)			1248.060	1313.377	803.283	573.614	1158.907	1442.135		
KOSDAQ(^KQ11)			218.022	164.284	112.088	69.589	133.400	133.053		
KOSPI(^KS11)			369.591	281.329	179.256	94.113	298.681	223.002		
일본 니케이(^N225)			1904.079	1080.955	3908.595	2711.546	5209.967	4703.504		
대만 기권(^TWII)			867.859	652.399	1103.165	1030.252	818.585	501.952		
비트코인 암호화폐(BTC-USD)			2865.359	2350.330	2406.506	2784.142	6169.101	6847.570		
Oil price(CL=F)			77.561	38.502	71.256	40.056	57.067	53.133		
이더리움 암호화폐(ETH-USD)			100.561	61.169	165.708	150.666	250.784	297.158		
Gold price(GC=F)			149.948	132.027	98.930	74.561	174.667	142.740		
10년 만기 미국 국채										
10년 만기 한국 국채										

Comparison results

- Root Mean Squared Error (Normalized to entire sequence)

Data	Proposed	Standard Deviation	RNN	Standard Deviation	LSTM	Standard Deviation	GRU	Standard Deviation	Enc-Dec LSTM	Standard Deviation
네덜란드 AEX(^AEX)			37.529	14.359	61.373	52.507	117.153	97.625		
인도 섀섹스(^BSESN)			3541.363	2346.927	2787.742	1512.201	5039.926	3927.614		
브라질 보베스파(^BVSP)			16483.670	5504.538	18074.670	19070.430	7416.942	6650.839		
다우존스(^DJI)			2814.726	1589.047	3821.574	2405.454	3871.976	3035.560		
프랑스 CAC(^FCHI)			819.126	521.972	834.549	546.485	637.017	423.104		
독일 DAX(^GDAXI)			1867.253	1312.073	3073.499	2846.996	2728.038	1915.373		
S&P 500(^GSPC)			471.864	519.321	412.896	372.110	445.756	416.998		
홍콩 항셱(^HSI)			4155.317	4889.277	3056.277	1629.809	3754.190	2629.909		
스페인 IBEX(^IBEX)			2359.103	2086.299	2676.277	2596.703	2417.470	1390.389		
NASDAQ(^IXIC)			1325.908	1381.195	872.247	582.379	1235.394	1548.914		
KOSDAQ(^KQ11)			231.067	168.337	116.986	70.903	139.067	134.067		
KOSPI(^KS11)			393.173	320.732	184.809	93.270	311.821	220.185		
일본 니케이(^N225)			2060.130	1134.687	4028.738	2707.807	5558.499	4787.983		
대만 기권(^TWII)			906.725	638.416	1140.091	1019.222	854.544	510.152		
비트코인 암호화폐(BTC-USD)			3301.660	2617.568	2855.275	3757.017	6733.202	7740.384		
Oil price(CL=F)			77.874	38.334	74.545	42.399	57.878	52.791		
이더리움 암호화폐(ETH-USD)			119.438	73.398	197.322	204.153	277.750	333.579		
Gold price(GC=F)			157.965	128.654	108.403	79.656	189.211	155.125		
10년 만기 미국 국채										
10년 만기 한국 국채										

Comparison results

- Mean Absolute Percentage Error ([Normalized to entire sequence](#))

Data	Proposed	Standard Deviation	RNN	Standard Deviation	LSTM	Standard Deviation	GRU	Standard Deviation	Enc-Dec LSTM	Standard Deviation
네덜란드 AEX(^AEX)			0.07161	0.03506	0.12503	0.12923	0.26499	0.23840		
인도 섹섹스(^BSESN)			0.10683	0.07398	0.09394	0.06837	0.16383	0.12501		
브라질 보베스파(^BVSP)			0.22794	0.08416	0.24355	0.19956	0.10234	0.09750		
다우존스(^DJI)			0.11774	0.05861	0.19649	0.13834	0.18048	0.15383		
프랑스 CAC(^FCHI)			0.17684	0.12203	0.17496	0.12372	0.13761	0.10833		
독일 DAX(^GDAXI)			0.16959	0.12433	0.31057	0.34273	0.25954	0.24711		
S&P 500(^GSPC)			0.20734	0.27143	0.16756	0.15141	0.21140	0.26450		
홍콩 항셱(^HSI)			0.14714	0.17476	0.11848	0.06427	0.15826	0.12347		
스페인 IBEX(^IBEX)			0.24021	0.19537	0.26932	0.23929	0.27122	0.19143		
NASDAQ(^IXIC)			0.21800	0.26560	0.13113	0.07755	0.26036	0.43043		
KOSDAQ(^KQ11)			0.31927	0.25213	0.15449	0.08666	0.19648	0.20427		
KOSPI(^KS11)			0.17500	0.12290	0.08805	0.04930	0.14592	0.11190		
일본 니케이(^N225)			0.10171	0.05449	0.22755	0.16474	0.33019	0.35294		
대만 기권(^TWII)			0.09674	0.08363	0.12224	0.12947	0.08744	0.06087		
비트코인 암호화폐(BTC-USD)			0.61058	0.41593	1.57680	2.60319	2.12815	2.85110		
Oil price(CL=F)			1.30848	0.58581	1.46967	1.40257	0.87250	0.74065		
이더리움 암호화폐(ETH-USD)			0.80664	0.98554	1.71497	2.88440	0.73274	0.61048		
Gold price(GC=F)			0.11358	0.10253	0.07152	0.05166	0.13588	0.11220		
10년 만기 미국 국채										
10년 만기 한국 국채										

Comparison results

- Mean Absolute Error (Comparison between different normalization)

Data	Proposed	RNN		LSTM		GRU		Enc-Dec LSTM
		Each seq	Entire seq	Each seq	Entire seq	Each seq	Entire seq	
네덜란드 AEX(^AEX)		9.700	33.674	9.072	55.825	12.169	115.306	
인도 섹스(^BSESN)		522.481	3176.914	757.710	2568.407	635.134	4821.795	
브라질 보베스파(^BVSP)		1531.036	15418.960	1529.299	17312.190	2040.192	7118.685	
다우존스(^DJI)		379.666	2543.574	386.981	3742.200	383.127	3769.545	
프랑스 CAC(^FCHI)		132.848	802.309	114.632	794.732	86.384	611.469	
독일 DAX(^GDAXI)		287.096	1827.681	236.222	2956.458	276.421	2599.160	
S&P 500(^GSPC)		45.127	459.890	40.281	391.832	33.122	431.442	
홍콩 항셱(^HSI)		625.978	3738.814	464.189	2977.772	592.841	3686.715	
스페인 IBEX(^IBEX)		223.378	2312.172	222.907	2620.912	245.819	2354.442	
NASDAQ(^IXIC)		109.496	1248.060	122.264	803.283	126.881	1158.907	
KOSDAQ(^KQ11)		27.665	218.022	25.220	112.088	23.798	133.400	
KOSPI(^KS11)		35.608	369.591	39.714	179.256	31.784	298.681	
일본 니케이(^N225)		537.349	1904.079	482.213	3908.595	539.397	5209.967	
대만 기권(^TWII)		159.542	867.859	172.253	1103.165	157.141	818.585	
비트코인 암호화폐(BTC-USD)		419.973	2865.359	325.423	2406.506	542.294	6169.101	
Oil price(CL=F)		2.953	77.561	1.990	71.256	2.678	57.067	
이더리움 암호화폐(ETH-USD)		40.476	100.561	28.455	165.708	27.205	250.784	
Gold price(GC=F)		21.052	149.948	20.112	98.930	22.077	174.667	
10년 만기 미국 국채								
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Comparison results

- Mean Squared Error (Comparison between different normalization)

Data	Proposed	RNN		LSTM		GRU		Enc-Dec LSTM
		Each seq	Entire seq	Each seq	Entire seq	Each seq	Entire seq	
네덜란드 AEX(^AEX)		11.304	37.529	10.566	61.373	14.227	117.153	
인도 섹스(^BSESN)		625.698	3541.363	869.819	2787.742	727.703	5039.926	
브라질 보베스파(^BVSP)		1858.968	16483.670	1829.228	18074.670	2366.848	7416.942	
다우존스(^DJI)		451.991	2814.726	447.909	3821.574	449.206	3871.976	
프랑스 CAC(^FCHI)		154.815	819.126	132.486	834.549	102.502	637.017	
독일 DAX(^GDAXI)		339.719	1867.253	274.045	3073.499	319.372	2728.038	
S&P 500(^GSPC)		52.531	471.864	47.002	412.896	39.627	445.756	
홍콩 항셱(^HSI)		751.627	4155.317	540.112	3056.277	687.794	3754.190	
스페인 IBEX(^IBEX)		262.575	2359.103	256.591	2676.277	278.552	2417.470	
NASDAQ(^IXIC)		127.552	1325.908	144.600	872.247	147.346	1235.394	
KOSDAQ(^KQ11)		31.153	231.067	29.395	116.986	27.159	139.067	
KOSPI(^KS11)		41.436	393.173	44.939	184.809	37.307	311.821	
일본 니케이(^N225)		610.658	2060.130	550.857	4028.738	614.475	5558.499	
대만 기권(^TWII)		183.530	906.725	197.271	1140.091	179.187	854.544	
비트코인 암호화폐(BTC-USD)		536.844	3301.660	427.415	2855.275	666.699	6733.202	
Oil price(CL=F)		3.894	77.874	2.794	74.545	3.594	57.878	
이더리움 암호화폐(ETH-USD)		50.980	119.438	36.175	197.322	34.514	277.750	
Gold price(GC=F)		26.200	157.965	25.728	108.403	28.299	189.211	
10년 만기 미국 국채								
10년 만기 한국 국채								

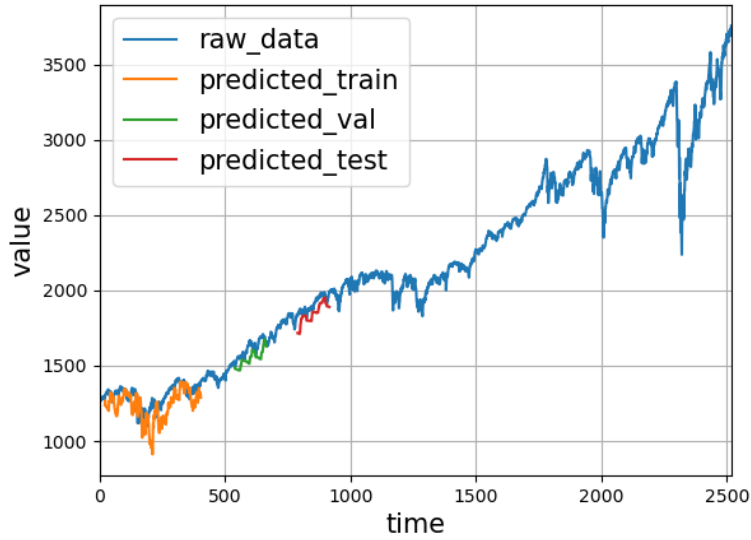
Comparison results

- Mean Absolute Percentage Error (**Comparison between different normalization**)

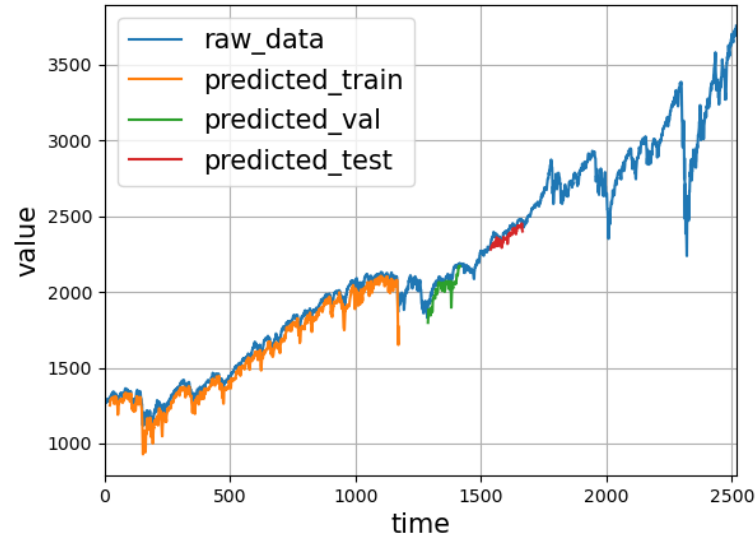
Data	Proposed	RNN		LSTM		GRU		Enc-Dec LSTM
		Each seq	Entire seq	Each seq	Entire seq	Each seq	Entire seq	
네덜란드 AEX(^AEX)		0.02149	0.07161	0.01938	0.12503	0.02651	0.26499	
인도 섹스(^BSESN)		0.01874	0.10683	0.02700	0.09394	0.02263	0.16383	
브라질 보베스파(^BVSP)		0.02367	0.22794	0.02444	0.24355	0.03200	0.10234	
다우존스(^DJI)		0.01884	0.11774	0.01926	0.19649	0.01879	0.18048	
프랑스 CAC(^FCHI)		0.02920	0.17684	0.02491	0.17496	0.01842	0.13761	
독일 DAX(^GDAXI)		0.02807	0.16959	0.02219	0.31057	0.02619	0.25954	
S&P 500(^GSPC)		0.01934	0.20734	0.01704	0.16756	0.01425	0.21140	
홍콩 항셱(^HSI)		0.02536	0.14714	0.01907	0.11848	0.02369	0.15826	
스페인 IBEX(^IBEX)		0.02469	0.24021	0.02437	0.26932	0.02631	0.27122	
NASDAQ(^IXIC)		0.01863	0.21800	0.02108	0.13113	0.02229	0.26036	
KOSDAQ(^KQ11)		0.03983	0.31927	0.03586	0.15449	0.03414	0.19648	
KOSPI(^KS11)		0.01690	0.17500	0.01907	0.08805	0.01553	0.14592	
일본 니케이(^N225)		0.03159	0.10171	0.02795	0.22755	0.03230	0.33019	
대만 기권(^TWII)		0.01696	0.09674	0.01824	0.12224	0.01643	0.08744	
비트코인 암호화폐(BTC-USD)		0.07405	0.61058	0.05769	1.57680	0.08609	2.12815	
Oil price(CL=F)		0.07050	1.30848	0.04872	1.46967	0.06203	0.87250	
이더리움 암호화폐(ETH-USD)		0.14305	0.80664	0.10787	1.71497	0.11357	0.73274	
Gold price(GC=F)		0.01556	0.11358	0.01484	0.07152	0.01643	0.13588	
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Comparison results

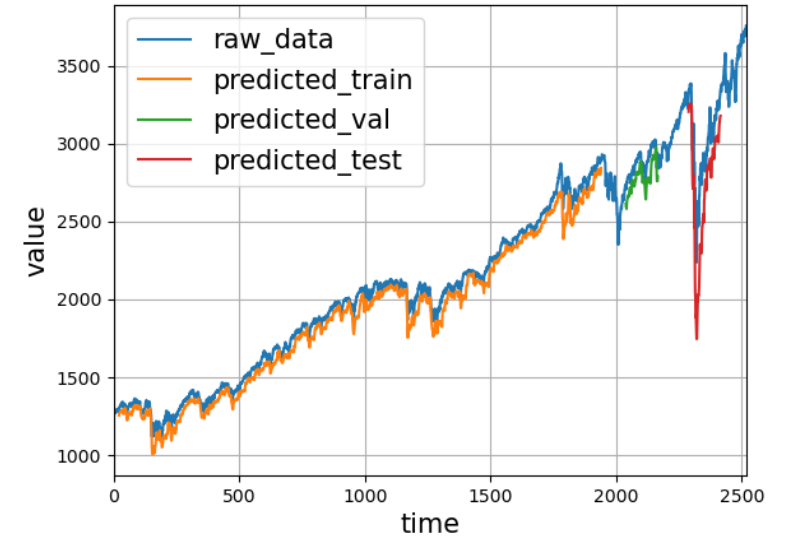
- Predicted Graph(LSTM – S&P 500 Index) –each seq



1th-Iteration



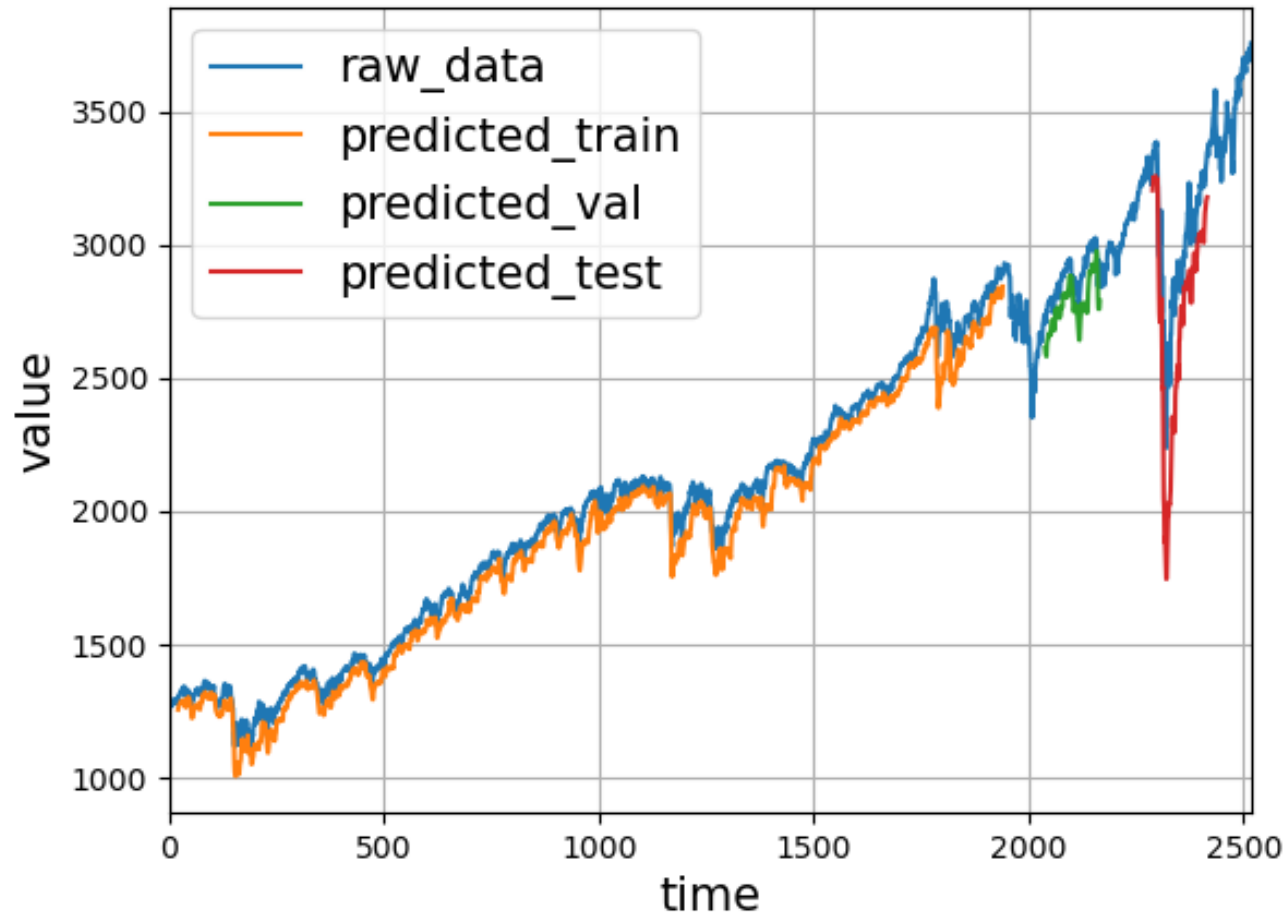
4th-Iteration



7th-Iteration

Comparison results

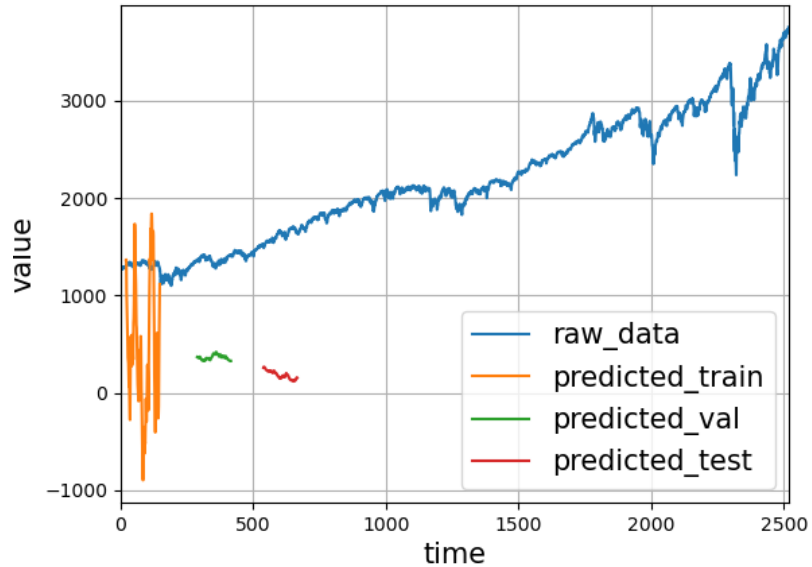
- Predicted Graph –each seq



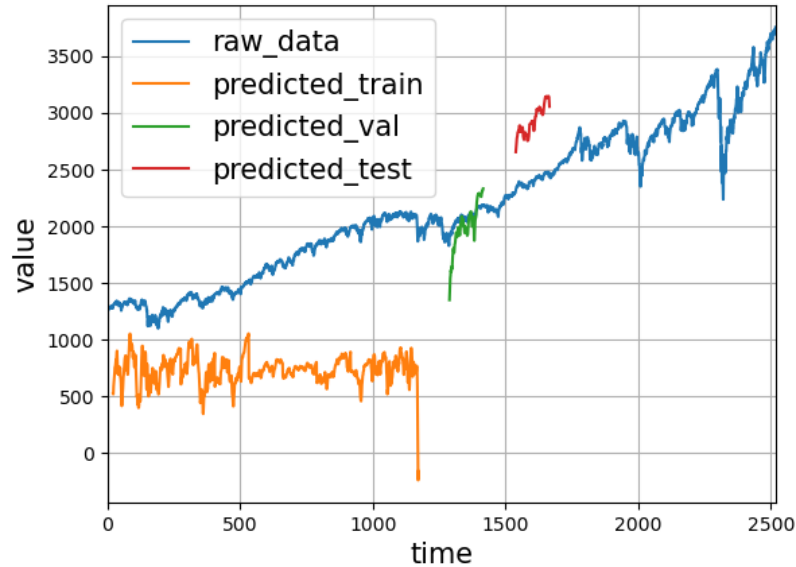
>> predicted value is lagged

Comparison results

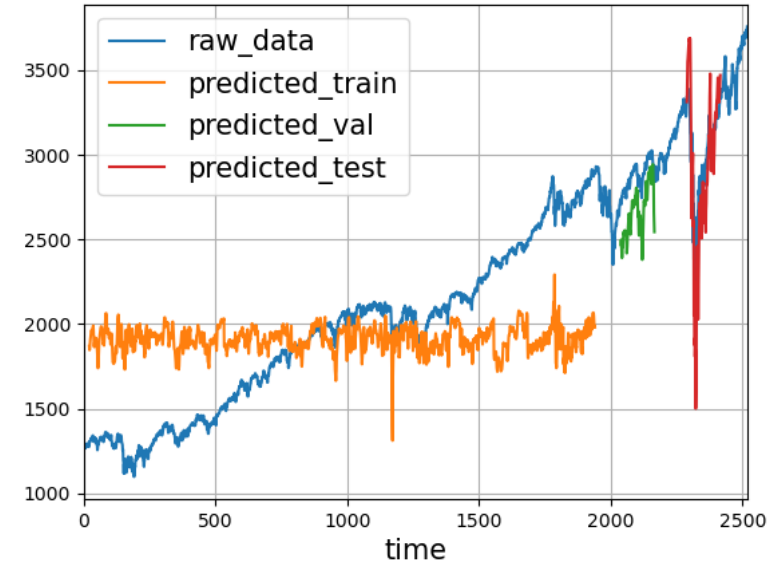
- Predicted Graph(LSTM – S&P 500 Index) – entire seq



1th-Iteration



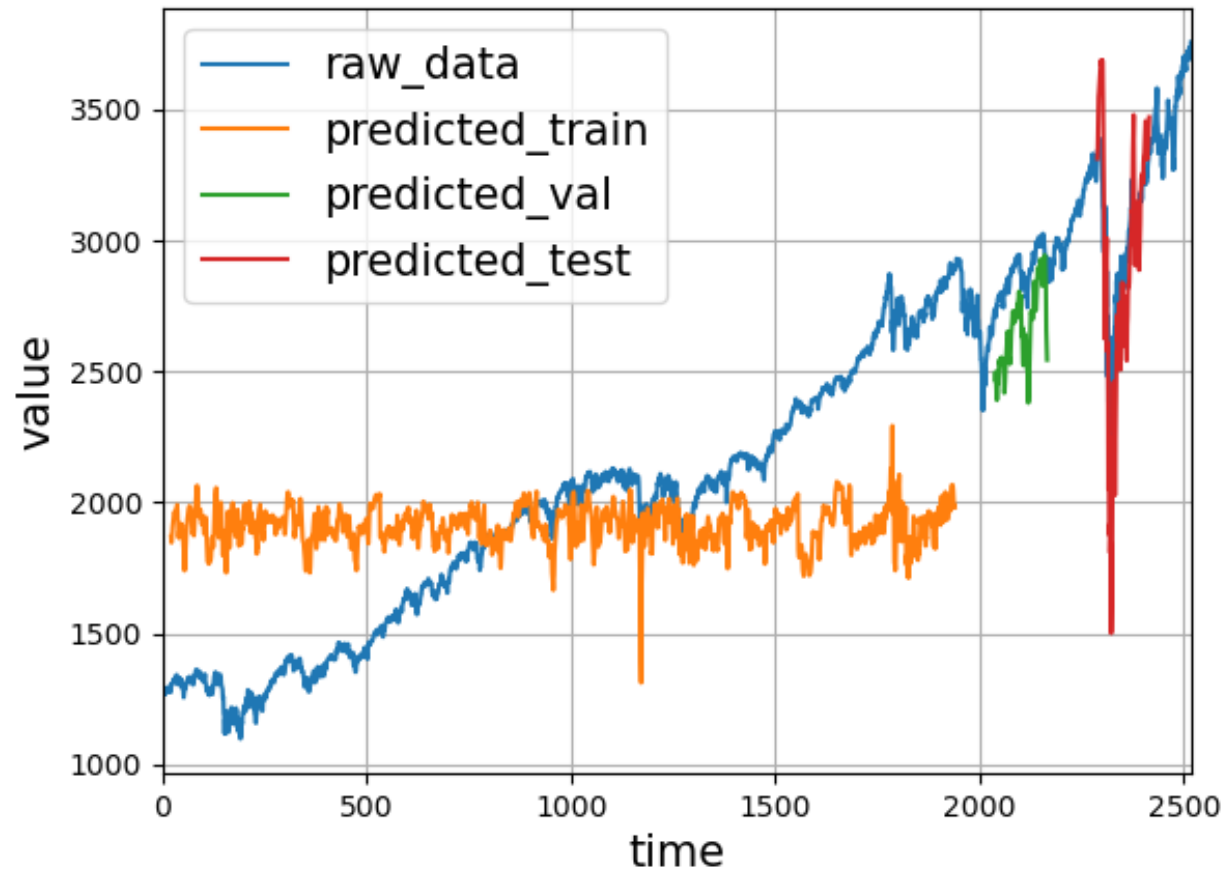
4th-Iteration



7th-Iteration

Comparison results

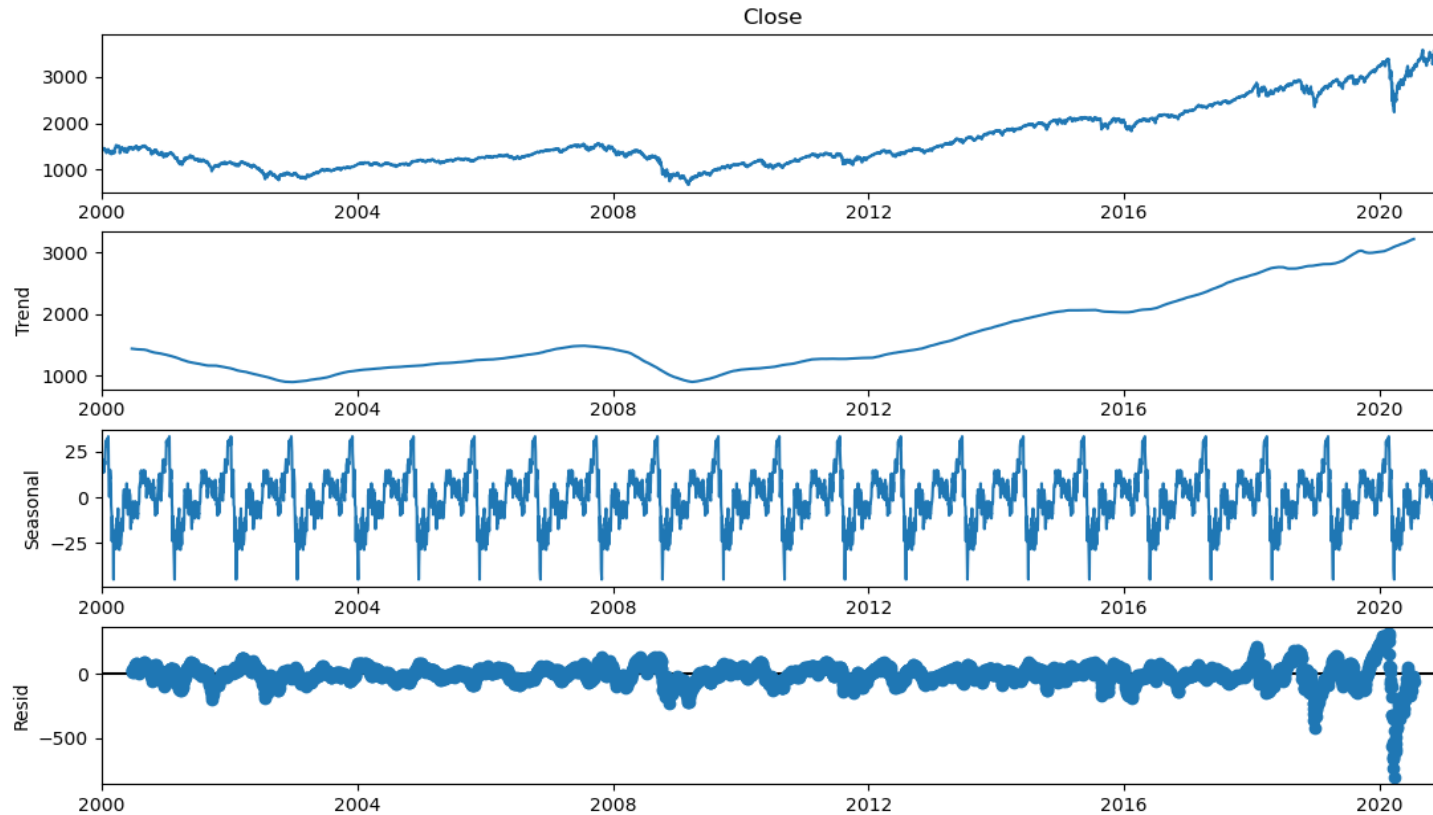
- Predicted Graph – entire seq



>> Not as good as normalization with each seq.

Issue

- Time series decomposition (S&P 500 Index)



>> 기존의 데이터를 Trend, seasonal, Residual로 분해하는 방식

>> 기존의 데이터에서 Trend, seasonal 두 값을 제외하면 Residual이 남는다.

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- 1 Ha Young Kim, & Chang Hyun Won (2018). Forecasting the volatility of stock price index: A hybrid model integrating LSTM with multiple GARCH-type models. Expert Systems With Applications, Vol.103. 25-37.
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<https://doi.org/10.1016/j.eswa.2020.114332>

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- 1 Ha Young Kim, & Chang Hyun Won (2018). Forecasting the volatility of stock price index: A hybrid model integrating LSTM with multiple GARCH-type models. Expert Systems With Applications, Vol.103. 25-37.
<https://doi.org/10.1016/j.eswa.2018.03.002>

Appendix

Appendix

- Jarque-bera test
 - 왜도와 첨도가 정규분포와 일치하는지 판단하는 적합도 검정
- ADF test
 - 시계열 데이터가 정상성(stationary)을 만족하는지에 대한 검정
- LM-ARCH 검정
 - ARCH, GARCH와 같은 모형을 적용할 수 있는지에 대한 검정.