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The forecast of the AGV battery discharging via the machine learning methods.

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Agenda

Research propose

Part 1. Data mining

1. Determine and collect the correlated parameters
2. Padding the lost data, allocating and fixing the incorrect data
3. Data normalization (bringing it to the range from 0 to 1)

Part 2. Build the ANN model

1. Choosing the type of the artificial neural network (ANN) for the forecast
2. Train and test the ANN

Part 3. Battery voltage fall forecast

1. Split data to the statical and dynamical parameters sets for the ANN inputs and outputs
2. Normalize all data [0,1]
3. Build the ANN model
4. ANN training and testing
5. ANN battery voltage forecast
6. Comparison the really measured battery voltage with the forecasts are obtained based on the statistical, and the ANN methods

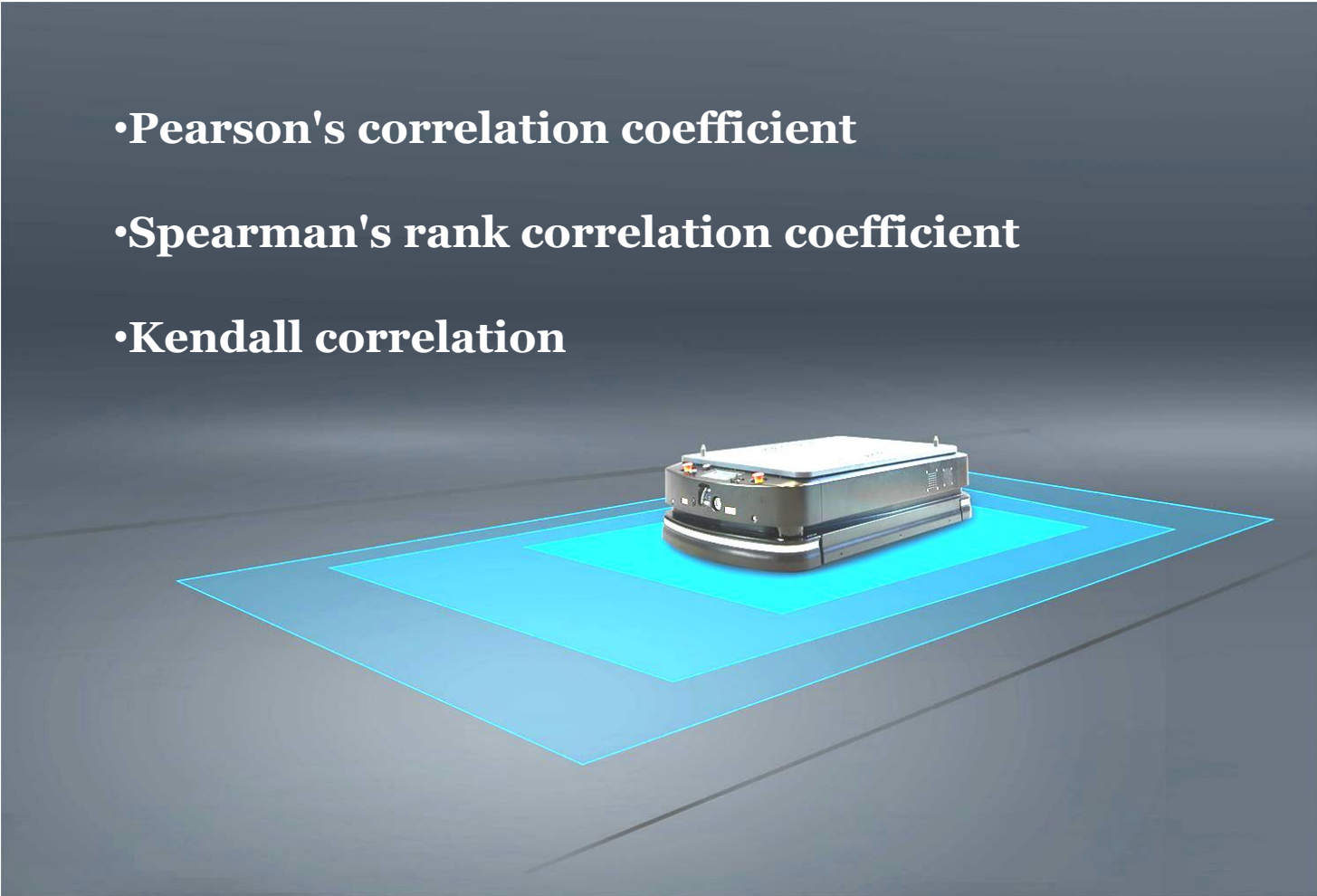
Future research planning



Part 1. Data mining

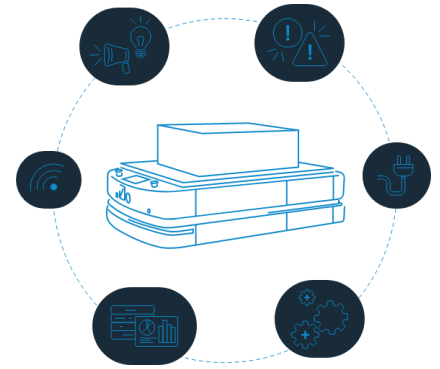
Determine and collect the correlated parameters

- **Pearson's correlation coefficient**
- **Spearman's rank correlation coefficient**
- **Kendall correlation**



Pearson's correlation coefficient

- 1 indicates a strong positive relationship;
- 1 indicates a strong negative relationship;
- 0 indicates the absence of the relationship.

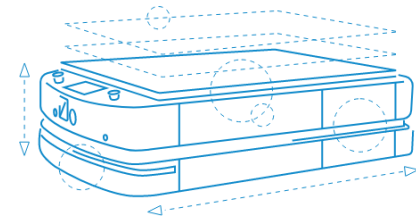


	BattCelVoltage	ComulEnCons	MomCurCons	MomEnCons	MomPovCons	CumDistL	CumDistR	MomFreqL	MomFreqR	CurSeg	Heading	XCoord	Ycoord	ActSpL	ActSpR
BattCelVoltage	1.000000	-0.995416	0.425204	0.425020	0.441440	nan	nan	0.135766	-0.076190	-0.389819	0.313924	0.176733	-0.037566	0.017678	0.002649
ComulEnCons	-0.995416	1.000000	-0.506560	-0.507054	-0.522029	nan	nan	-0.144082	0.087568	0.431240	-0.347577	-0.215445	0.057883	-0.016251	-0.001316
MomCurCons	0.425204	-0.506560	1.000000	0.986795	0.999810	nan	nan	0.150434	-0.131421	-0.583602	0.470300	0.421205	-0.184377	-0.013460	-0.020922
MomEnCons	0.425020	-0.507054	0.986795	1.000000	0.986767	nan	nan	0.155613	-0.134445	-0.583617	0.472168	0.431284	-0.196697	-0.015572	-0.019580
MomPovCons	0.441440	-0.522029	0.999810	0.986767	1.000000	nan	nan	0.151209	-0.132041	-0.585913	0.471611	0.421173	-0.183053	-0.013192	-0.021011
CumDistL	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
CumDistR	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
MomFreqL	0.135766	-0.144082	0.150434	0.155613	0.151209	nan	nan	1.000000	0.084695	-0.055383	0.115859	0.042812	-0.145644	0.045820	0.053802
MomFreqR	-0.076190	0.087568	-0.131421	-0.134445	-0.132041	nan	nan	0.084695	1.000000	0.093041	-0.100983	-0.068912	0.023284	-0.033605	-0.028691
CurSeg	-0.389819	0.431240	-0.583602	-0.583617	-0.585913	nan	nan	-0.055383	0.093041	1.000000	-0.194382	-0.681174	-0.392822	-0.037187	-0.033393
Heading	0.313924	-0.347577	0.470300	0.472168	0.471611	nan	nan	0.115859	-0.100983	-0.194382	1.000000	0.023033	-0.432615	-0.002347	-0.002931
XCoord	0.176733	-0.215445	0.421205	0.431284	0.421173	nan	nan	0.042812	-0.068912	-0.681174	0.023033	1.000000	0.169827	0.016056	0.010446
Ycoord	-0.037566	0.057883	-0.184377	-0.196697	-0.183053	nan	nan	-0.145644	0.023284	-0.392822	-0.432615	0.169827	1.000000	0.013900	0.014365
ActSpL	0.017678	-0.016251	-0.013460	-0.015572	-0.013192	nan	nan	0.045820	-0.033605	-0.037187	-0.002347	0.016056	0.013900	1.000000	0.974870
ActSpR	0.002649	-0.001316	-0.020922	-0.019580	-0.021011	nan	nan	0.053802	-0.028691	-0.033393	-0.002931	0.010446	0.014365	0.974870	1.000000

Pearson's correlation coefficient

17.06.2022y. Original data. AGV with no load

	Momentary current consumption	Battery cell voltage	Momentary power consumption	Momentary energy consumption	Cumulative energy consumption	Speed
Momentary current consumption	1.000000	-0.213202	0.998911	0.875553	0.162223	-0.016900
Battery cell voltage	-0.213202	1.000000	-0.168622	-0.189549	-0.996227	-0.007582
Momentary power consumption	0.998911	-0.168622	1.000000	0.875033	0.117187	-0.017519
Momentary energy consumption	0.875553	-0.189549	0.875033	1.000000	0.134181	-0.020006
Cumulative energy consumption	0.162223	-0.996227	0.117187	0.134181	1.000000	0.007567
Speed	-0.016900	-0.007582	-0.017519	-0.020006	0.007567	1.000000



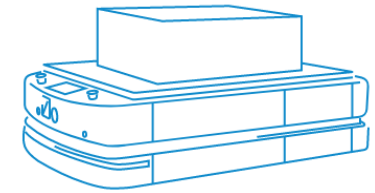
Normalized data
to the range
from 0 to 1.
(no load on AGV)

	Momentary current consumption	Momentary power consumption	Momentary energy consumption	Speed	Battery cell voltage	Cumulative energy consumption
Momentary current consumption	1.000000	0.999435	0.998184	-0.007976	0.898659	0.420514
Momentary power consumption	0.999435	1.000000	0.998665	-0.008057	0.906492	0.389965
Momentary energy consumption	0.998184	0.998665	1.000000	-0.012300	0.903436	0.391683
Speed	-0.007976	-0.008057	-0.012300	1.000000	0.010328	0.005350
Battery cell voltage	0.898659	0.906492	0.903436	0.010328	1.000000	0.172363
Cumulative energy consumption	0.420514	0.389965	0.391683	0.005350	0.172363	1.000000

Pearson's correlation coefficient

01.07.2022 y. Original data AGV with load (600 kg.)

	Momentary current consumption	Battery cell voltage	Momentary power consumption	Momentary energy consumption
Momentary current consumption	1.000000	0.776239	0.040290	-0.053355
Battery cell voltage	0.776239	1.000000	0.055705	-0.069420
Momentary power consumption	0.040290	0.055705	1.000000	-0.986709
Momentary energy consumption	-0.053355	-0.069420	-0.986709	1.000000

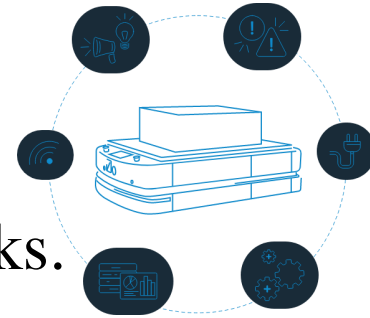


Normalized data (range from 0 to 1) AGV with load (600 kg.)

	Momentary current consumption	Momentary power consumption	Momentary energy consumption	Battery cell voltage
Momentary current consumption	1.000000	0.387451	0.860274	0.990965
Momentary power consumption	0.387451	1.000000	0.092339	0.396909
Momentary energy consumption	0.860274	0.092339	1.000000	0.862324
Battery cell voltage	0.990965	0.396909	0.862324	1.000000

Spearman's rank correlation coefficient

- 1 if the observations have similar ranks;
- -1 low when the observations have the different ranks.

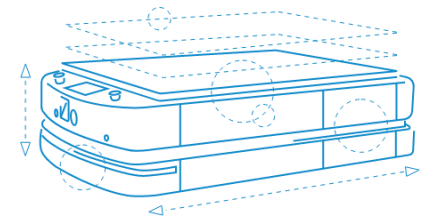


	BattCelVoltage	ComulEnCons	MomCurCons	MomEnCons	MomPovCons	CumDistL	CumDistR	MomFreqL	MomFreqR	CurSeg	Heading	XCoord	Ycoord	ActSpL	ActSpR
BattCelVoltage	1.000000	-0.975513	0.511313	0.566491	0.563970	nan	nan	0.185494	-0.010613	-0.515742	0.316294	0.139651	0.028831	0.010055	0.008823
ComulEnCons	-0.975513	1.000000	-0.589551	-0.636954	-0.636692	nan	nan	-0.215509	0.008764	0.540198	-0.372988	-0.134088	0.014771	0.005273	0.008249
MomCurCons	0.511313	-0.589551	1.000000	0.925995	0.994803	nan	nan	0.128436	-0.073541	-0.577479	0.379858	0.298232	-0.032631	-0.112683	-0.120183
MomEnCons	0.566491	-0.636954	0.925995	1.000000	0.932391	nan	nan	0.126796	-0.085040	-0.583677	0.381444	0.306463	-0.032278	-0.109119	-0.107732
MomPovCons	0.563970	-0.636692	0.994803	0.932391	1.000000	nan	nan	0.127822	-0.076558	-0.585749	0.374047	0.301227	-0.023150	-0.108929	-0.115287
CumDistL	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
CumDistR	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
MomFreqL	0.185494	-0.215509	0.128436	0.126796	0.127822	nan	nan	1.000000	0.185990	-0.087053	0.154420	0.008563	-0.134655	0.034878	0.039804
MomFreqR	-0.010613	0.008764	-0.073541	-0.085040	-0.076558	nan	nan	0.185990	1.000000	0.081733	-0.014174	-0.086487	-0.046522	-0.046599	-0.040923
CurSeg	-0.515742	0.540198	-0.577479	-0.583677	-0.585749	nan	nan	-0.087053	0.081733	1.000000	-0.067111	-0.692369	-0.430461	0.053836	0.051101
Heading	0.316294	-0.372988	0.379858	0.381444	0.374047	nan	nan	0.154420	-0.014174	-0.067111	1.000000	-0.097232	-0.600153	-0.015728	-0.021941
XCoord	0.139651	-0.134088	0.298232	0.306463	0.301227	nan	nan	0.008563	-0.086487	-0.692369	-0.097232	1.000000	0.326145	-0.002213	0.000303
Ycoord	0.028831	0.014771	-0.032631	-0.032278	-0.023150	nan	nan	-0.134655	-0.046522	-0.430461	-0.600153	0.326145	1.000000	0.008284	0.014245
ActSpL	0.010055	0.005273	-0.112683	-0.109119	-0.108929	nan	nan	0.034878	-0.046599	0.053836	-0.015728	-0.002213	0.008284	1.000000	0.963321
ActSpR	0.008823	0.008249	-0.120183	-0.107732	-0.115287	nan	nan	0.039804	-0.040923	0.051101	-0.021941	0.000303	0.014245	0.963321	1.000000

Spearman's rank correlation coefficient

17.06.2022y. Original data. AGV with no load

	Momentary current consumption	Battery cell voltage	Momentary power consumption	Momentary energy consumption	Cumulative energy consumption	Speed
Momentary current consumption	1.000000	-0.076644	0.956542	0.746613	0.062293	-0.114158
Battery cell voltage	-0.076644	1.000000	0.143855	0.112538	-0.999510	-0.001158
Momentary power consumption	0.956542	0.143855	1.000000	0.777947	-0.158140	-0.097016
Momentary energy consumption	0.746613	0.112538	0.777947	1.000000	-0.128292	-0.092534
Cumulative energy consumption	0.062293	-0.999510	-0.158140	-0.128292	1.000000	0.001847
Speed	-0.114158	-0.001158	-0.097016	-0.092534	0.001847	1.000000

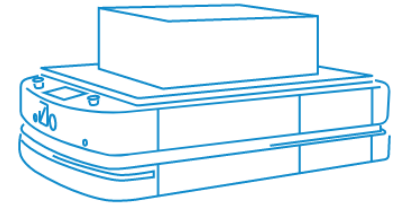


Normalized data
to the range
from 0 to 1.
(no load on AGV)

	Momentary current consumption	Momentary power consumption	Momentary energy consumption	Speed	Battery cell voltage	Cumulative energy consumption
Momentary current consumption	1.000000	0.974219	0.957570	-0.139638	0.154892	0.312583
Momentary power consumption	0.974219	1.000000	0.980899	-0.136359	0.304281	0.148715
Momentary energy consumption	0.957570	0.980899	1.000000	-0.144538	0.298609	0.155301
Speed	-0.139638	-0.136359	-0.144538	1.000000	-0.001272	-0.007370
Battery cell voltage	0.154892	0.304281	0.298609	-0.001272	1.000000	-0.607704
Cumulative energy consumption	0.312583	0.148715	0.155301	-0.007370	-0.607704	1.000000

Spearman's rank correlation coefficient

01.07.2022 y. Original data AGV with load (600 kg.)



	Momentary current consumption	Battery cell voltage	Momentary power consumption	Momentary energy consumption
Momentary current consumption	1.000000	0.737589	0.045760	-0.053275
Battery cell voltage	0.737589	1.000000	0.066238	-0.074084
Momentary power consumption	0.045760	0.066238	1.000000	-0.988069
Momentary energy consumption	-0.053275	-0.074084	-0.988069	1.000000

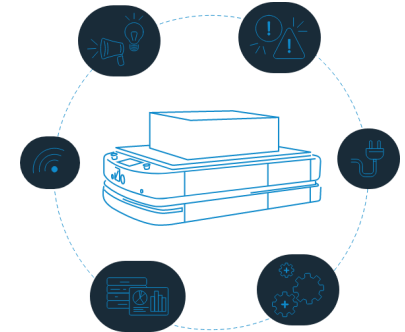
Normalized data (range from 0 to 1) AGV with load (600 kg.)

	Momentary current consumption	Momentary power consumption	Momentary energy consumption	Battery cell voltage
Momentary current consumption	1.000000	0.348784	0.057475	0.978793
Momentary power consumption	0.348784	1.000000	-0.655374	0.352786
Momentary energy consumption	0.057475	-0.655374	1.000000	0.053473
Battery cell voltage	0.978793	0.352786	0.053473	1.000000

Kendall correlation

Tests the association between paired samples

using the Pearson, Kendall, or Spearman methods

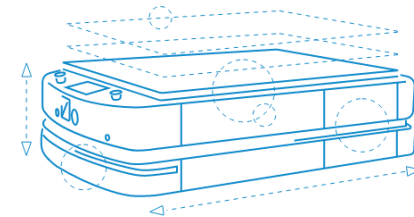


	BattCelVoltage	ComulEnCons	MomCurCons	MomEnCons	MomPovCons	CumDistL	CumDistR	MomFreqL	MomFreqR	CurSeg	Heading	XCoord	Ycoord	ActSpL	ActSpR
BattCelVoltage	1.000000	-0.942178	0.358589	0.406692	0.407886	nan	nan	0.121505	-0.029532	-0.367005	0.215344	0.114107	0.044943	0.018020	0.014950
ComulEnCons	-0.942178	1.000000	-0.418461	-0.465868	-0.466844	nan	nan	-0.136448	0.023427	0.390712	-0.264454	-0.100969	0.005266	0.001933	0.004827
MomCurCons	0.358589	-0.418461	1.000000	0.814381	0.964000	nan	nan	0.103968	-0.028199	-0.444156	0.276489	0.203000	-0.028685	-0.061552	-0.061309
MomEnCons	0.406692	-0.465868	0.814381	1.000000	0.818221	nan	nan	0.102758	-0.031695	-0.445510	0.279174	0.204298	-0.031647	-0.053690	-0.042892
MomPovCons	0.407886	-0.466844	0.964000	0.818221	1.000000	nan	nan	0.101939	-0.029615	-0.446462	0.270277	0.202686	-0.023320	-0.059195	-0.057701
CumDistL	nan	nan	nan	nan	nan	1.000000	nan	nan	nan	nan	nan	nan	nan	nan	nan
CumDistR	nan	nan	nan	nan	nan	nan	1.000000	nan	nan	nan	nan	nan	nan	nan	nan
MomFreqL	0.121505	-0.136448	0.103968	0.102758	0.101939	nan	nan	1.000000	0.181894	-0.070879	0.118864	0.003332	-0.117810	0.026332	0.029603
MomFreqR	-0.029532	0.023427	-0.028199	-0.031695	-0.029615	nan	nan	0.181894	1.000000	0.048054	0.005227	-0.075917	-0.059849	-0.036510	-0.035314
CurSeg	-0.367005	0.390712	-0.444156	-0.445510	-0.446462	nan	nan	-0.070879	0.048054	1.000000	-0.100737	-0.518125	-0.274525	0.019892	0.017620
Heading	0.215344	-0.264454	0.276489	0.279174	0.270277	nan	nan	0.118864	0.005227	-0.100737	1.000000	-0.108701	-0.480570	-0.011970	-0.016653
XCoord	0.114107	-0.100969	0.203000	0.204298	0.202686	nan	nan	0.003332	-0.075917	-0.518125	-0.108701	1.000000	0.290903	0.002666	0.007403
Ycoord	0.044943	0.005266	-0.028685	-0.031647	-0.023320	nan	nan	-0.117810	-0.059849	-0.274525	-0.480570	0.290903	1.000000	0.008196	0.013712
ActSpL	0.018020	0.001933	-0.061552	-0.053690	-0.059195	nan	nan	0.026332	-0.036510	0.019892	-0.011970	0.002666	0.008196	1.000000	0.846346
ActSpR	0.014950	0.004827	-0.061309	-0.042892	-0.057701	nan	nan	0.029603	-0.035314	0.017620	-0.016653	0.007403	0.013712	0.846346	1.000000

Kendall correlation

17.06.2022y. Original data. AGV with no load

	Momentary current consumption	Battery cell voltage	Momentary power consumption	Momentary energy consumption	Cumulative energy consumption	Speed
Momentary current consumption	1.000000	-0.054771	0.888836	0.614222	0.044422	-0.071975
Battery cell voltage	-0.054771	1.000000	0.110812	0.082765	-0.986865	-0.001286
Momentary power consumption	0.888836	0.110812	1.000000	0.643173	-0.119885	-0.059439
Momentary energy consumption	0.614222	0.082765	0.643173	1.000000	-0.093005	-0.053934
Cumulative energy consumption	0.044422	-0.986865	-0.119885	-0.093005	1.000000	0.002550
Speed	-0.071975	-0.001286	-0.059439	-0.053934	0.002550	1.000000



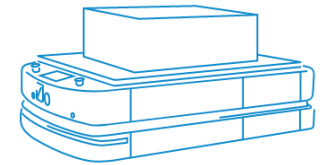
Normalized data
to the range
from 0 to 1.
(no load on AGV)

	Momentary current consumption	Momentary power consumption	Momentary energy consumption	Speed	Battery cell voltage	Cumulative energy consumption
Momentary current consumption	1.000000	0.875224	0.839532	-0.093635	0.092720	0.225043
Momentary power consumption	0.875224	1.000000	0.909721	-0.086158	0.217339	0.100414
Momentary energy consumption	0.839532	0.909721	1.000000	-0.093041	0.213984	0.103760
Speed	-0.093635	-0.086158	-0.093041	1.000000	-0.001236	-0.003590
Battery cell voltage	0.092720	0.217339	0.213984	-0.001236	1.000000	-0.680141
Cumulative energy consumption	0.225043	0.100414	0.103760	-0.003590	-0.680141	1.000000

Kendall correlation

01.07.2022 y. Original data AGV with load (600 kg.)

	Momentary current consumption	Battery cell voltage	Momentary power consumption	Momentary energy consumption
Momentary current consumption	1.000000	0.586660	0.029250	-0.037516
Battery cell voltage	0.586660	1.000000	0.042540	-0.051794
Momentary power consumption	0.029250	0.042540	1.000000	-0.921762
Momentary energy consumption	-0.037516	-0.051794	-0.921762	1.000000

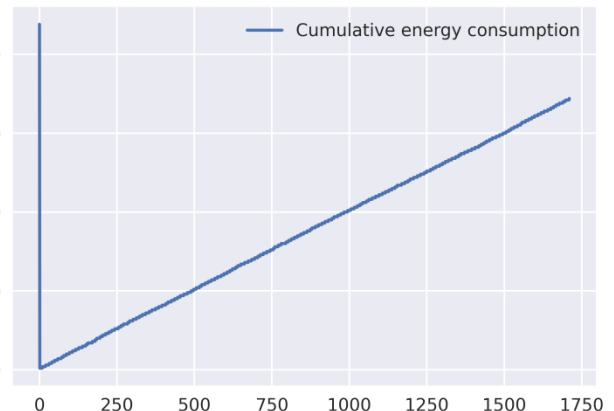
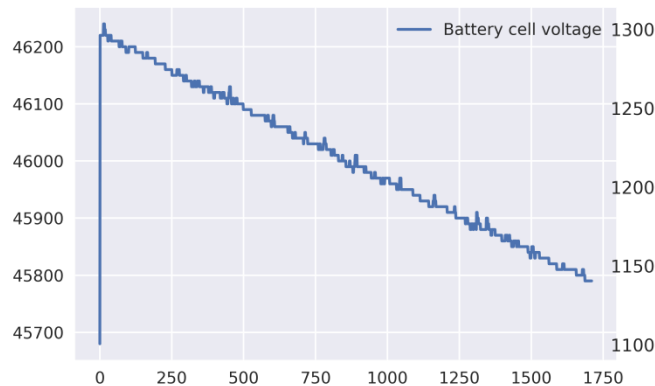
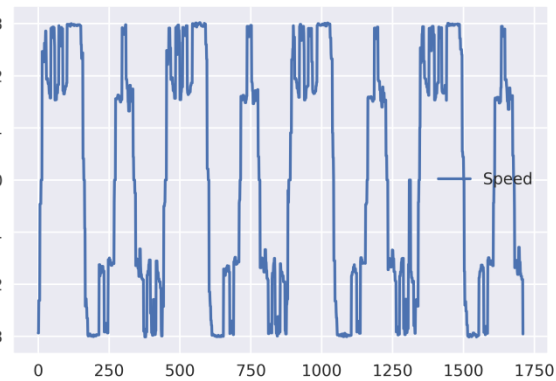
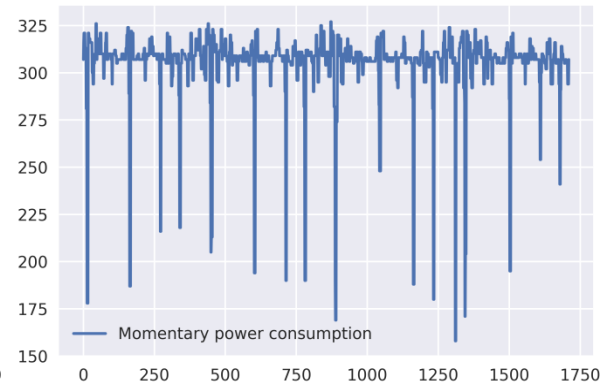
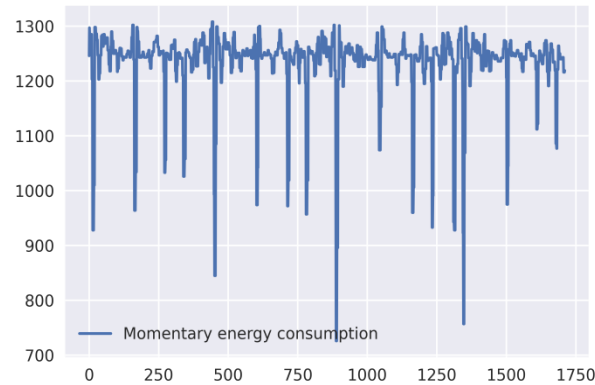
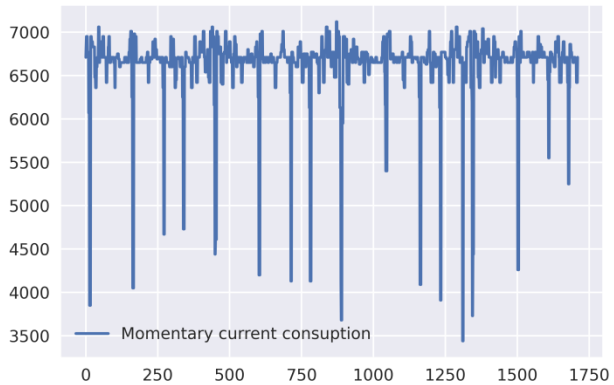


Normalized data (range from 0 to 1) AGV with load (600 kg.)

	Momentary current consumption	Momentary power consumption	Momentary energy consumption	Battery cell voltage
Momentary current consumption	1.000000	0.236613	0.034715	0.884160
Momentary power consumption	0.236613	1.000000	-0.674578	0.240634
Momentary energy consumption	0.034715	-0.674578	1.000000	0.031030
Battery cell voltage	0.884160	0.240634	0.031030	1.000000

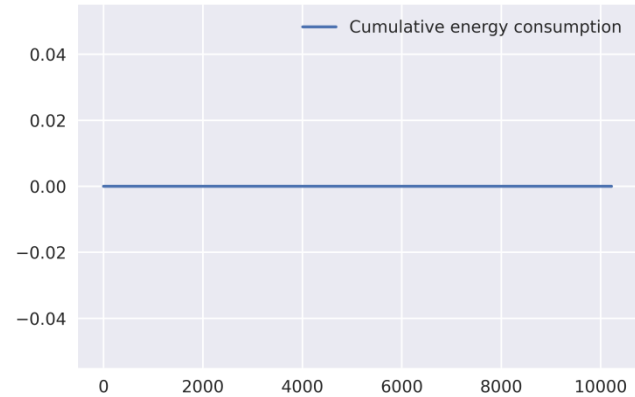
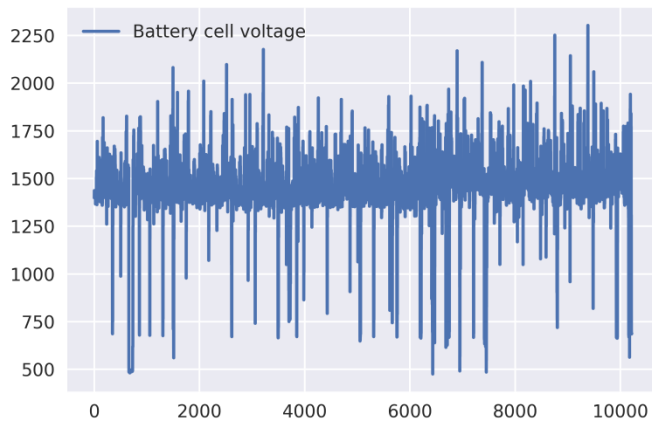
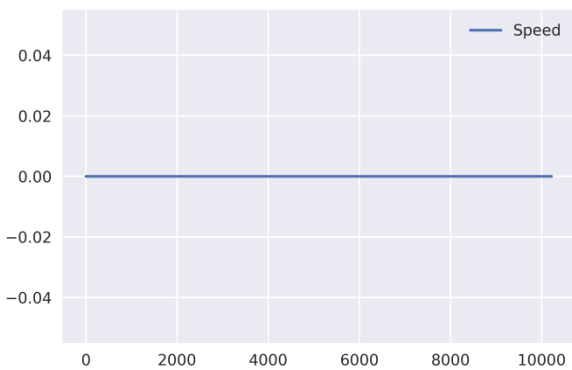
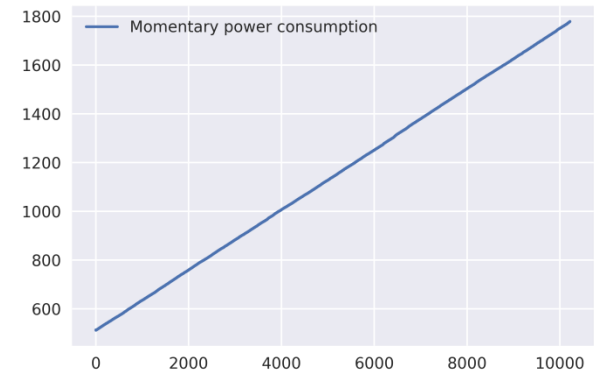
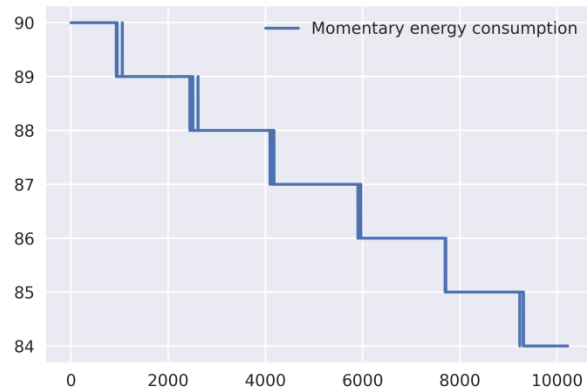
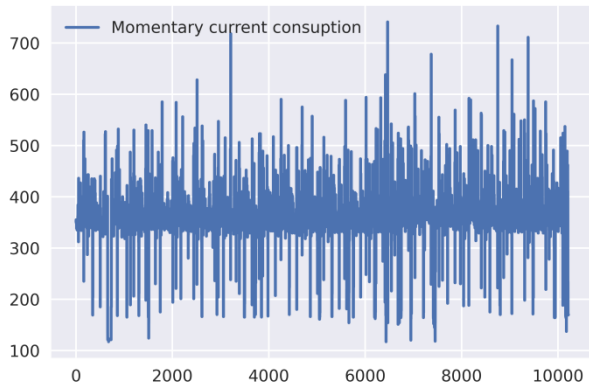
Correlated parameters

10.06.2022 y. AGV with no load



Correlated parameters

01.07.2022 y. AGV with load (600 kg.)



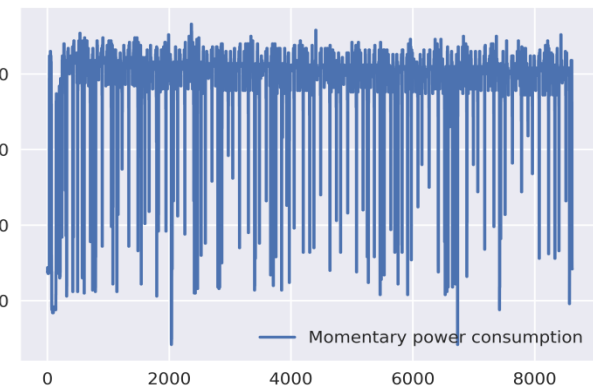
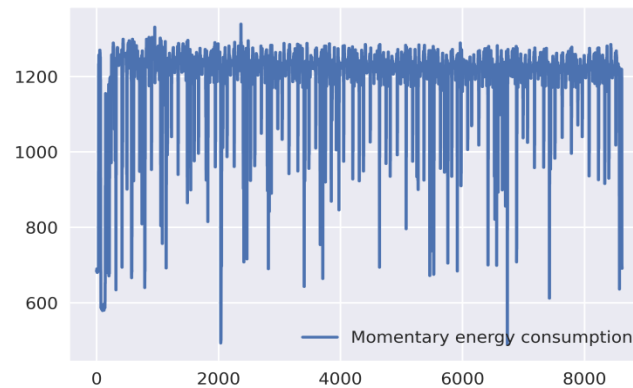
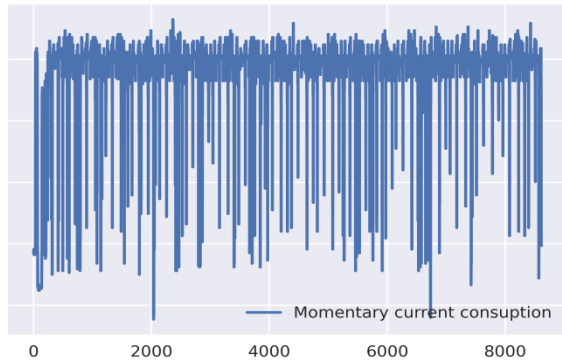
1. 2. Padding the lost data, allocating and recovering the incorrect data

In scope of the data padding

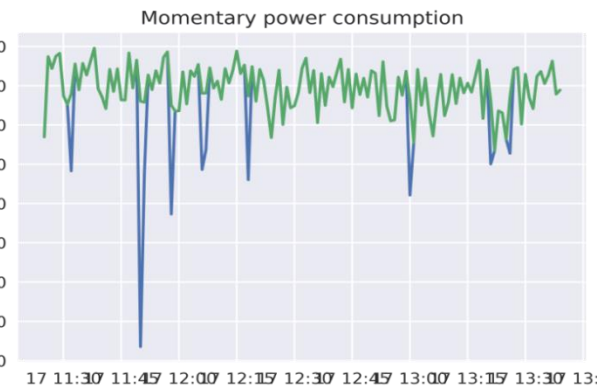
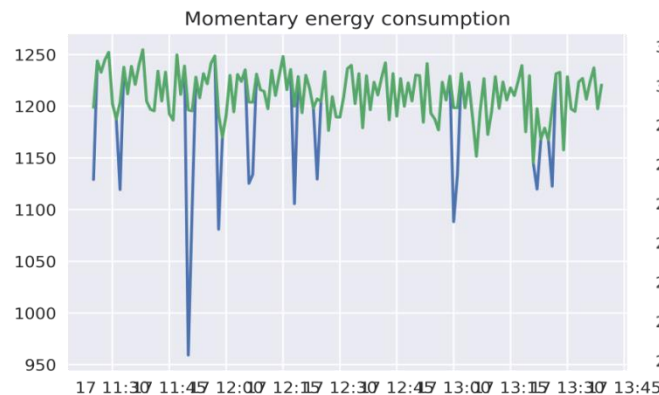
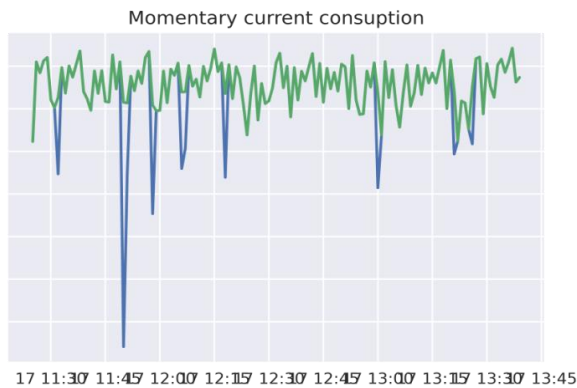
- Nans where replaced with the previous values
- Accidental peaks suppression: values that exceed the 1.5 variances (e.g. RMSE) are replaced with the moving average value
- Trimming the start and end values in the time window range
- Bringing data to the range from 0 to 1

17.06.2022 y. AGV with no load

Original data

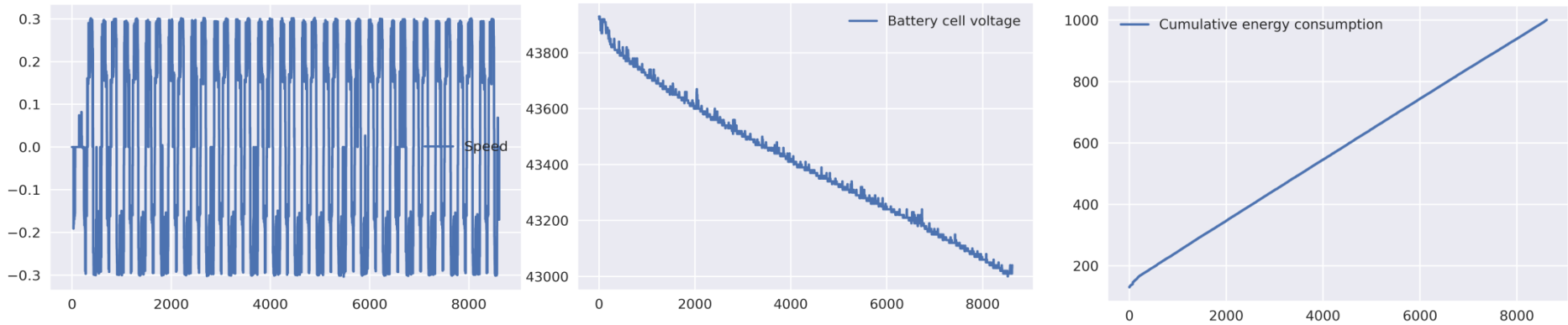


Accidental peaks suppression whose values exceed the 1.5 variances

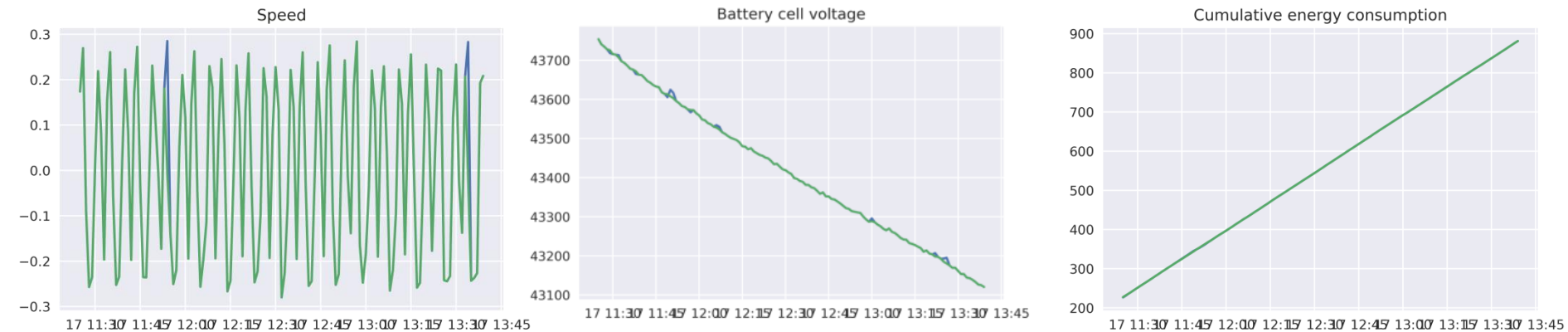


17.06.2022 y. AGV with no load

Original data

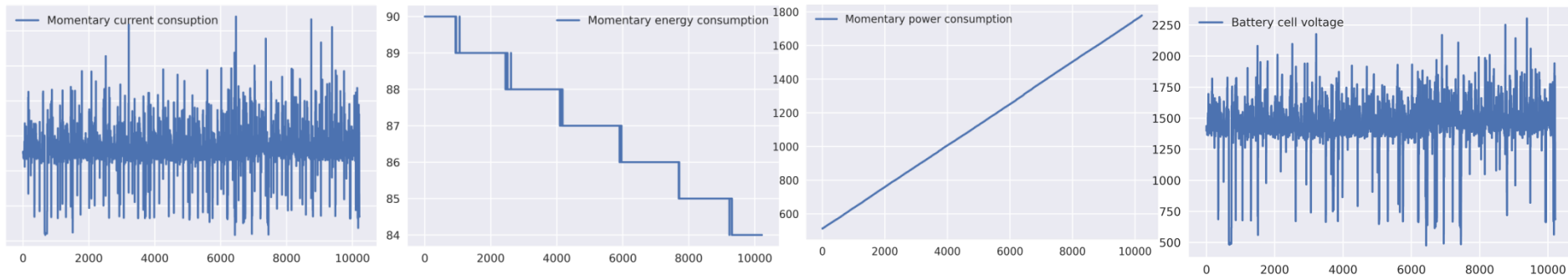


Accidental peaks suppression whose values exceed the 1.5 variances

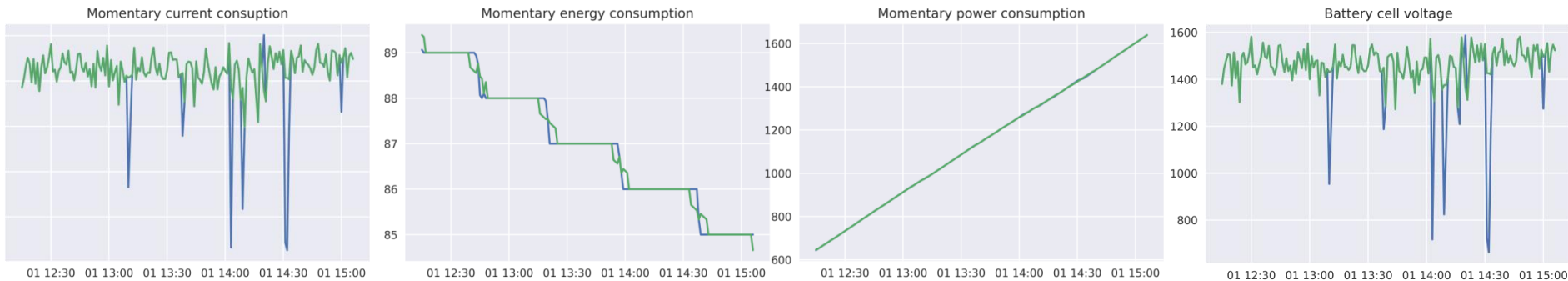


01.07.2022 y. AGV with load (600 kg.)

Original data



Accidental peaks suppression whose values exceed the 1.5 variances



1. 3. Data normalization

- bringing to the range from 0 to 1

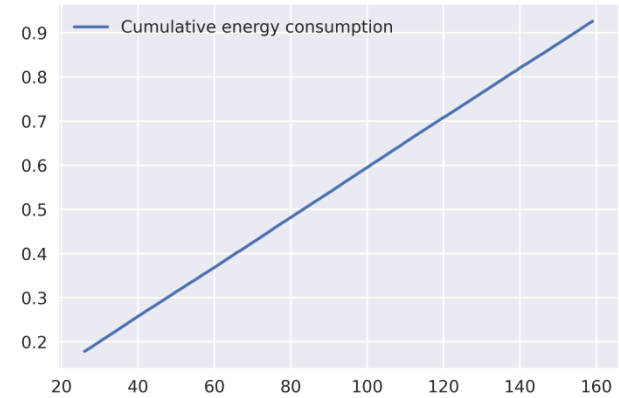
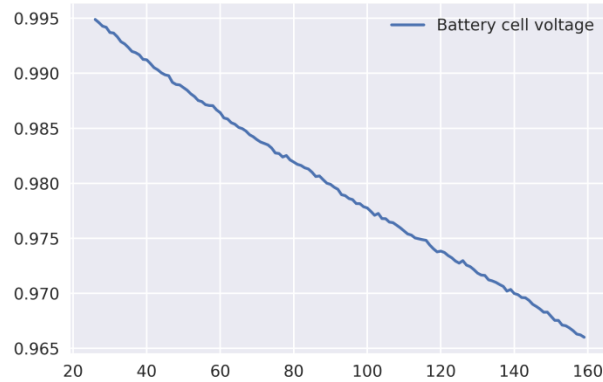
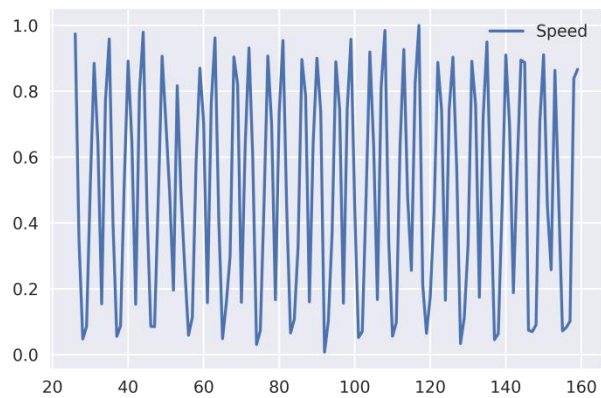
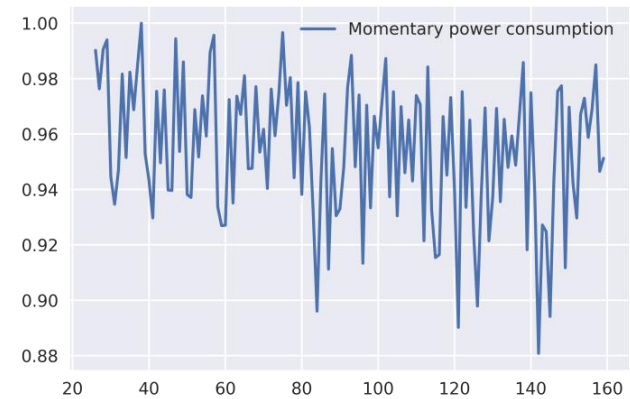
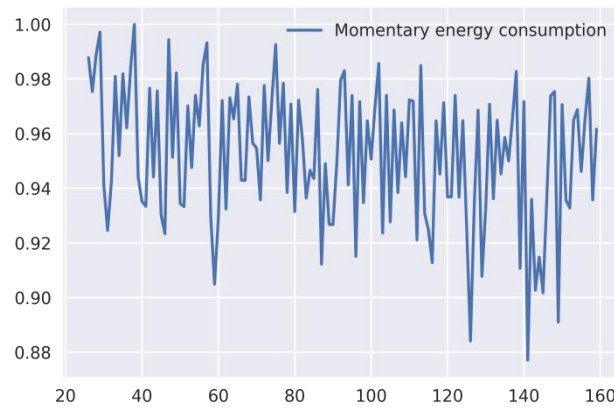
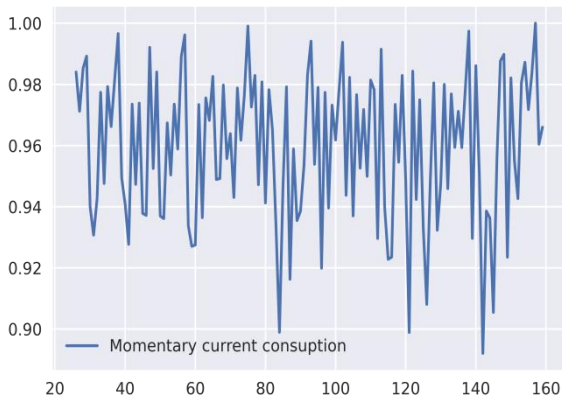
$$\tilde{x}_i = \frac{x_i - x_{i,min}}{x_{i,max} - x_{i,min}}$$

- transfer to the initial range of values

$$x_i = \tilde{x}_i (x_{i,max} - x_{i,min}) + x_{i,min}$$

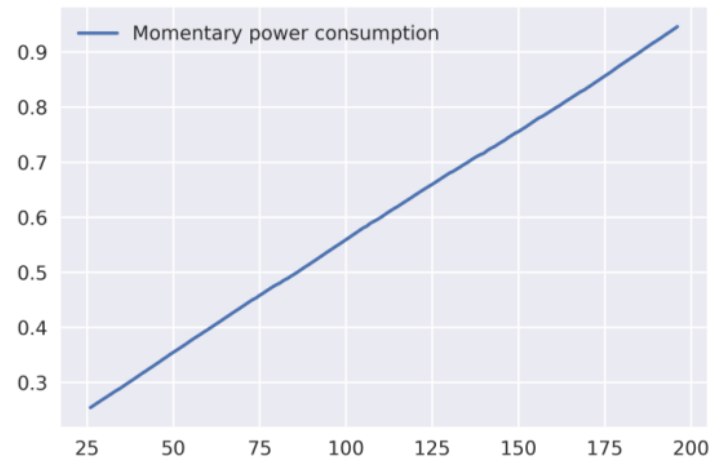
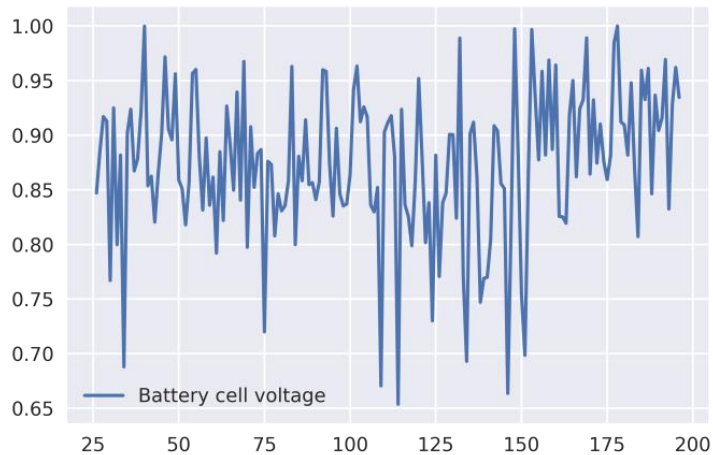
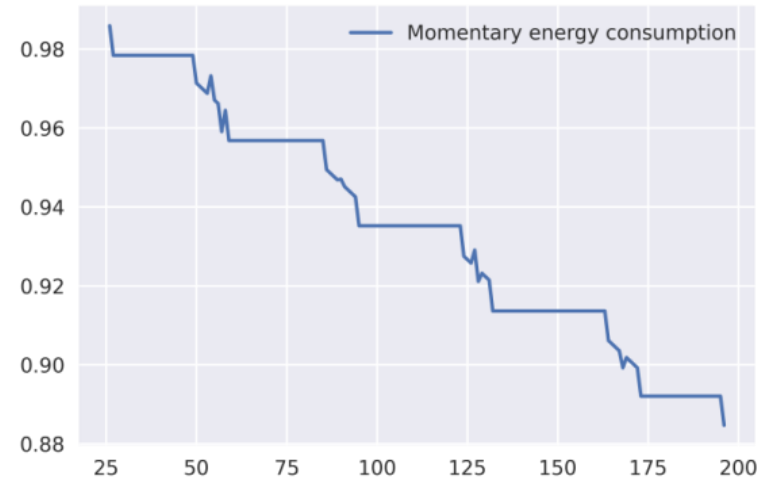
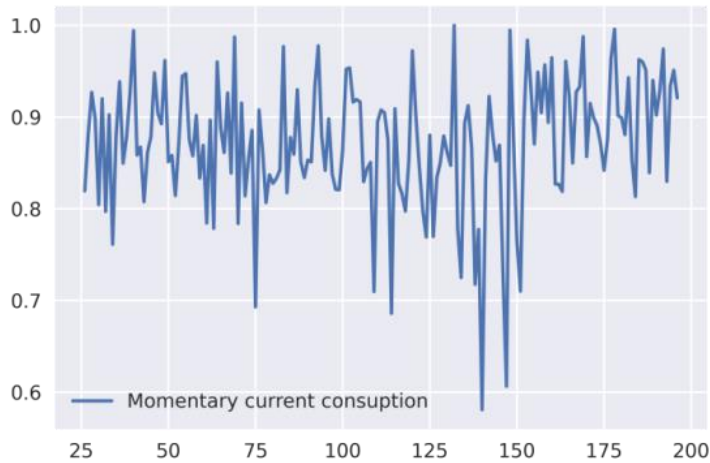
Data padding and normalization

17.06.2022 AGV no load



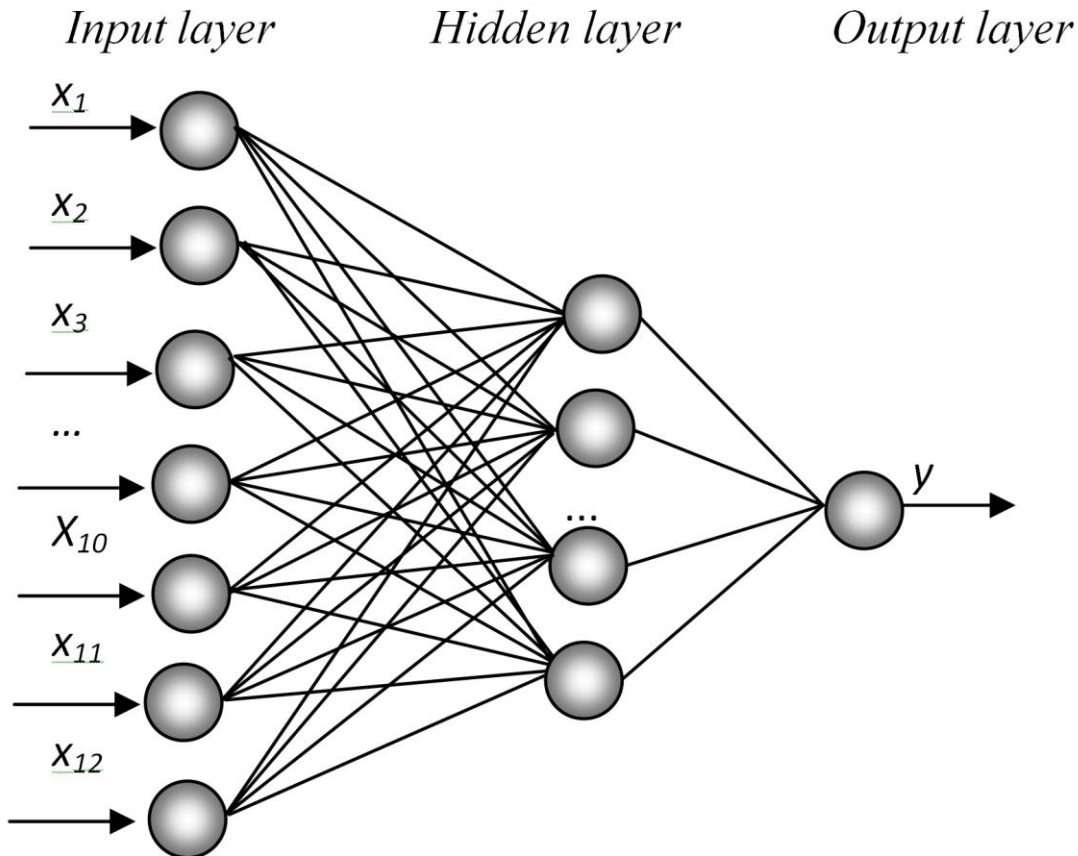
Data padding and normalization

01.07.2022 y. AGV with load (600 kg.)



2.1. Choosing the type of artificial neural network for the forecasting

The structure of the ANN

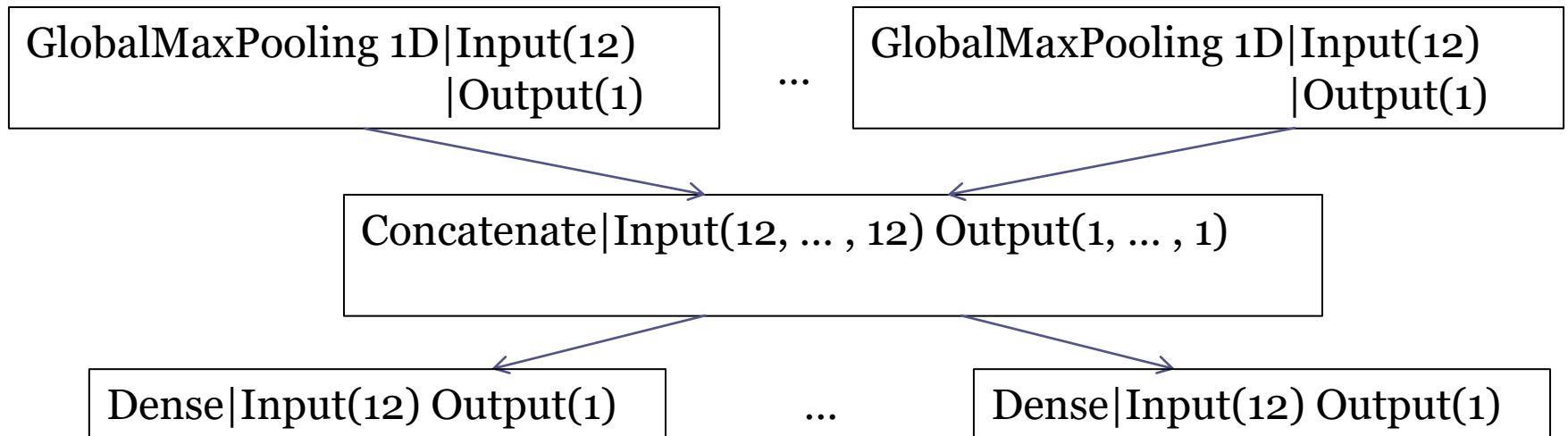


In the experimental way I determined the ANN parameters:

- **Input layer:** 12 neurons per input parameter
- **Hidden layer:** 8 neurons per output parameter
- **Output layer:** 1 neuron per output parameter

Model ANN

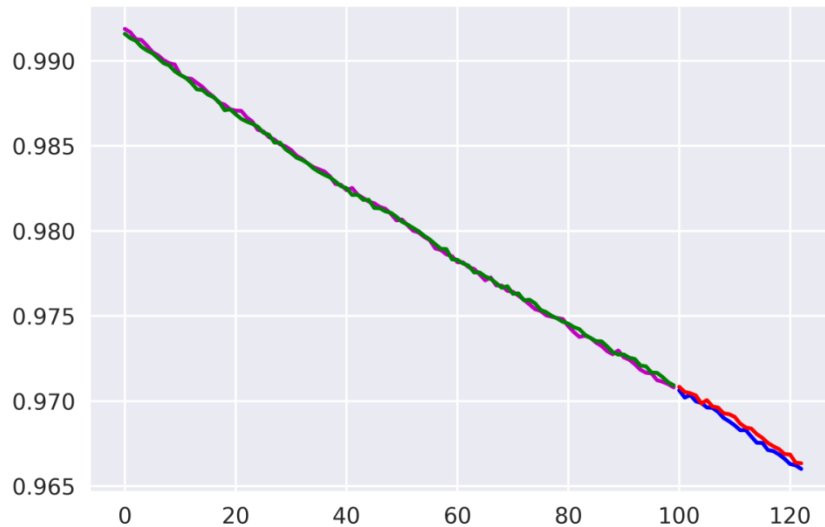
Input signals: momentary current consumption, momentary power consumption, momentary energy consumption



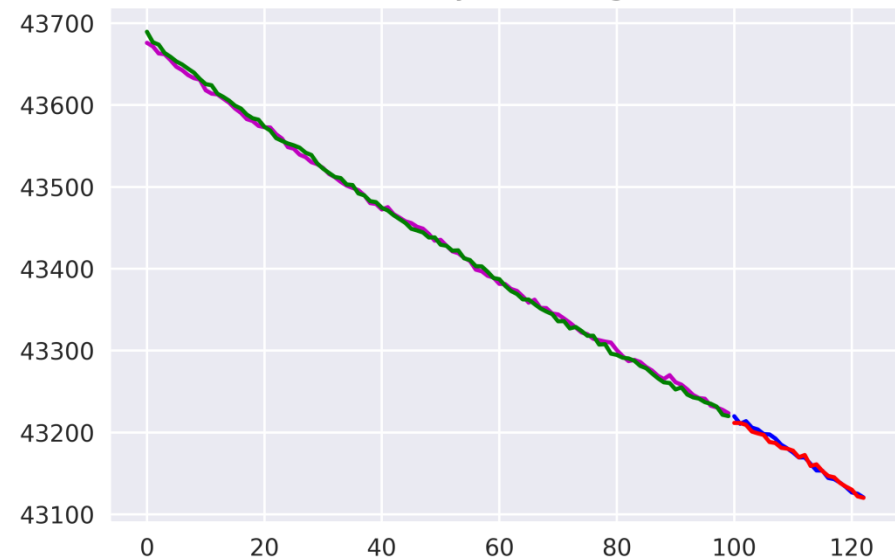
Training and testing the ANN (17.06.2022 y. AGV with no load)

Mean absolute percentage error (%)	Learn	Predict
with normalize	0.0170	0.0319
without normalize	0.0092	0.0072

Battery cell voltage



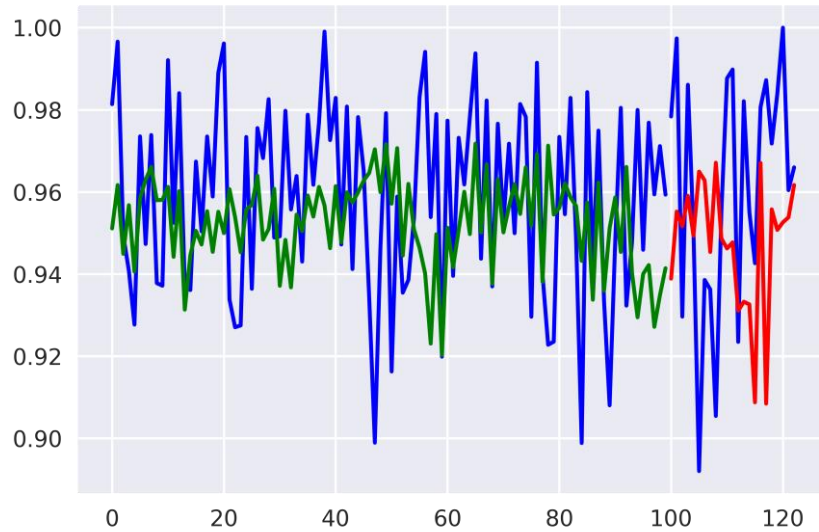
Battery cell voltage



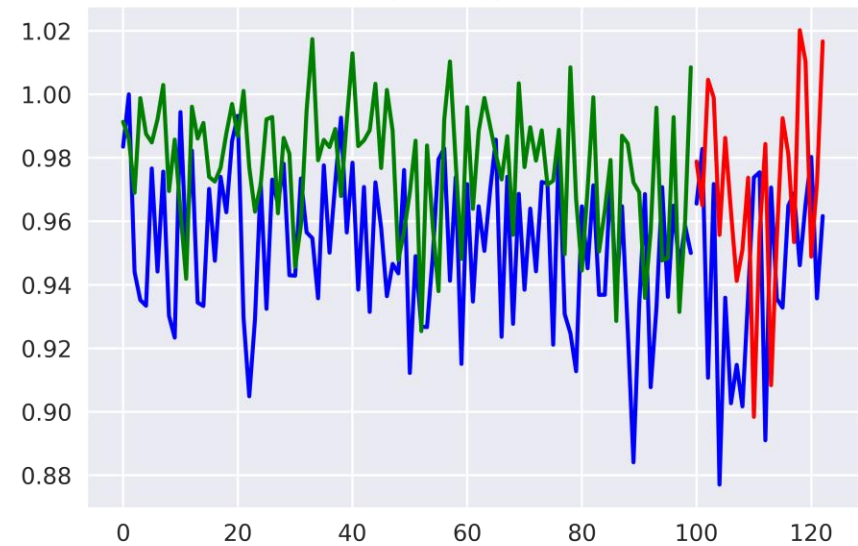
2.2. Training and testing the ANN

(17.06.2022 y. AGV with no load, normalized)

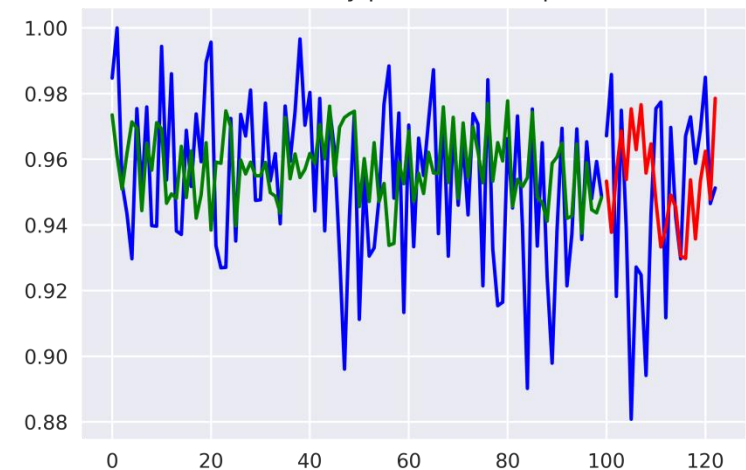
Momentary current consumption



Momentary energy consumption



Momentary power consumption



Mean absolute percentage error (%)

- Momentary current consumption 2.6173
- Momentary power consumption 2.3812
- Momentary energy consumption 3.0108

Learn Predict

3.1815

3.0477

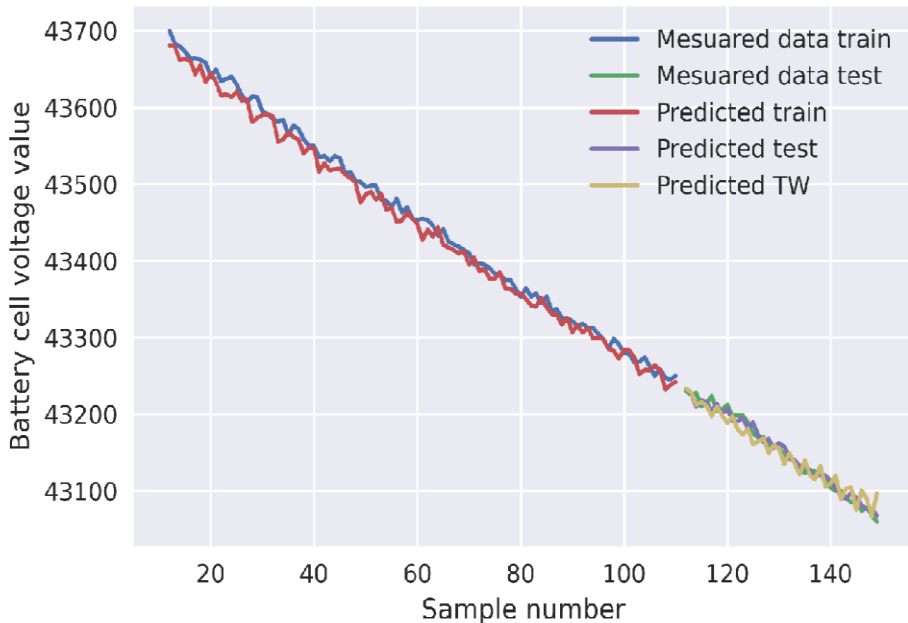
4.9233

Training and testing the ANN

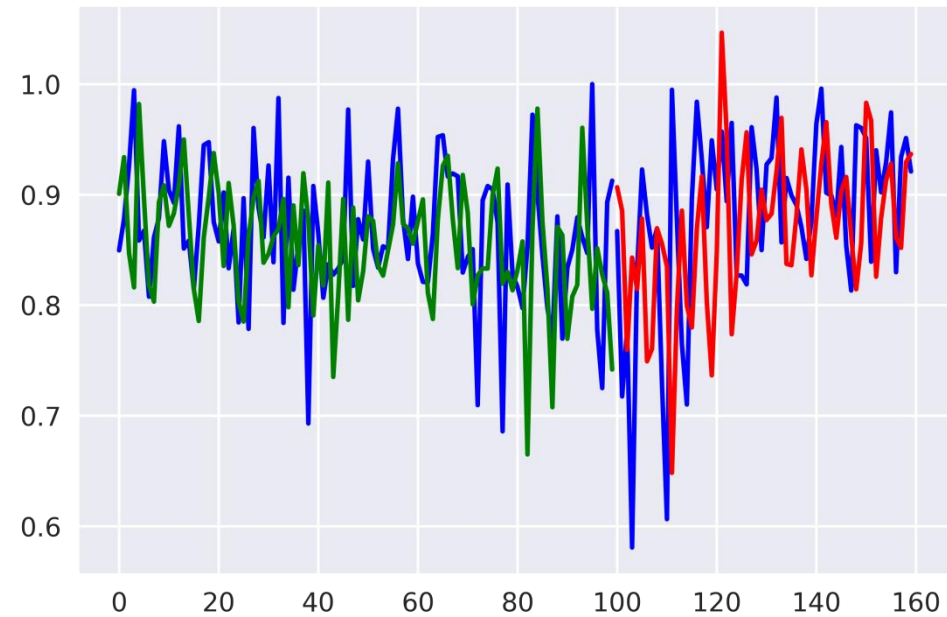
01.07.2022 y. AGV with load (600 kg.), normalized

Mean absolute percentage error (%)	Learn	Predict
Momentary current consumption:	7.1547	9.6943
Battery cell voltage:	0.029	0.005

Battery cell voltage



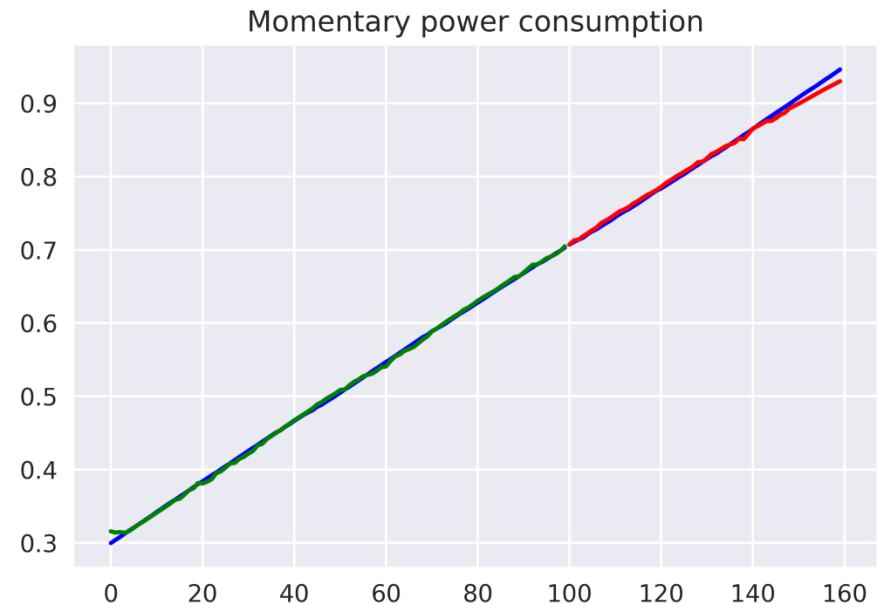
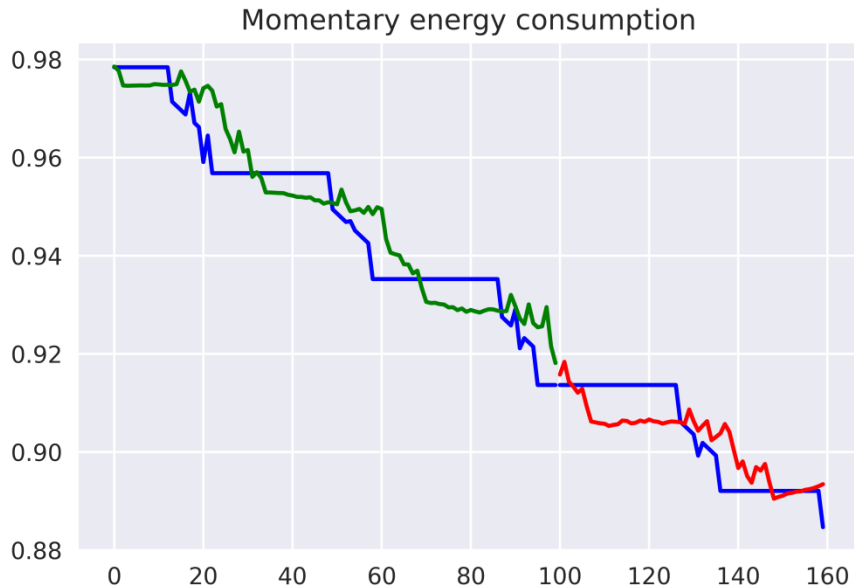
Momentary current consumption



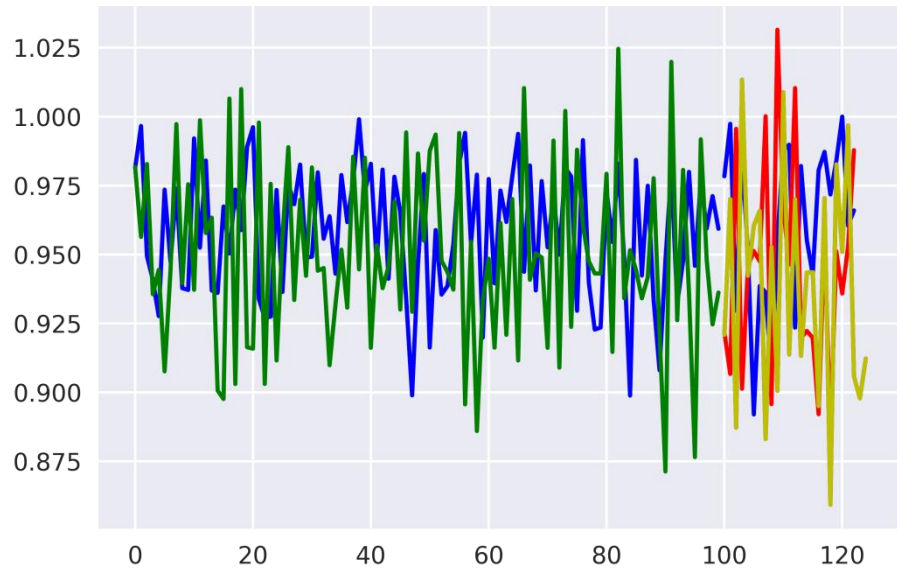
Training and testing the ANN

01.07.2022 y. AGV with load (600 kg.), normalized

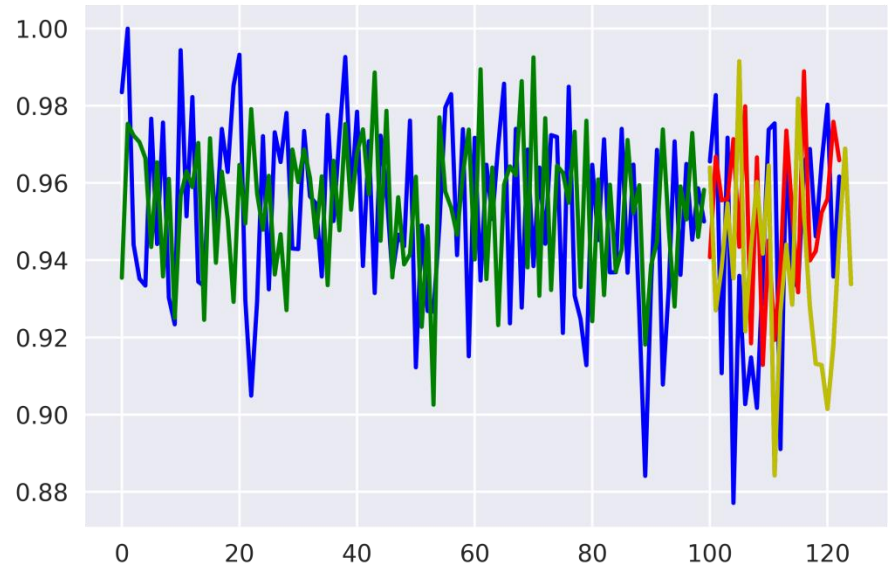
Mean absolute percentage error (%)	Learn	Predict
Momentary energy consumption:	0.5906	0.5294
Momentary power consumption :	0.4874	0.5216



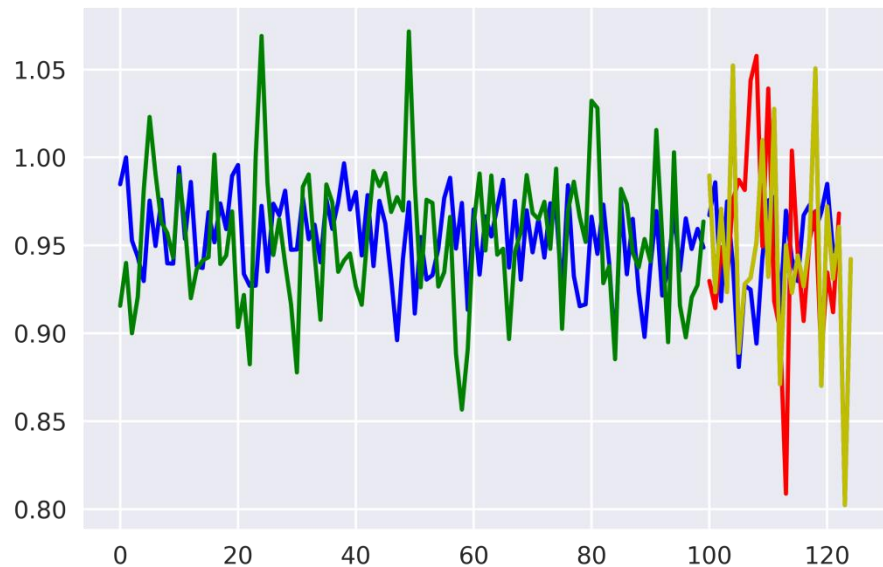
Momentary current consumption



Momentary energy consumption



Momentary power consumption



the blue - is the measured samples from the training set.

the green - ANN test on the learning data set

the red - ANN test on the testing data set

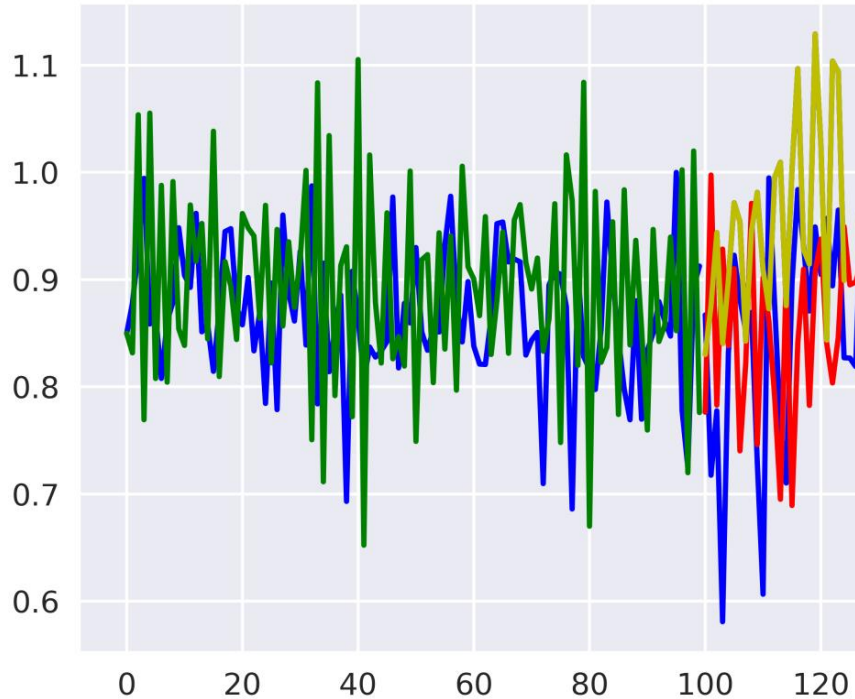
the yellow - forecast result using the window time shifting method and the trained ANN model over the testing data set

17.06.2022 y. AGV with no load

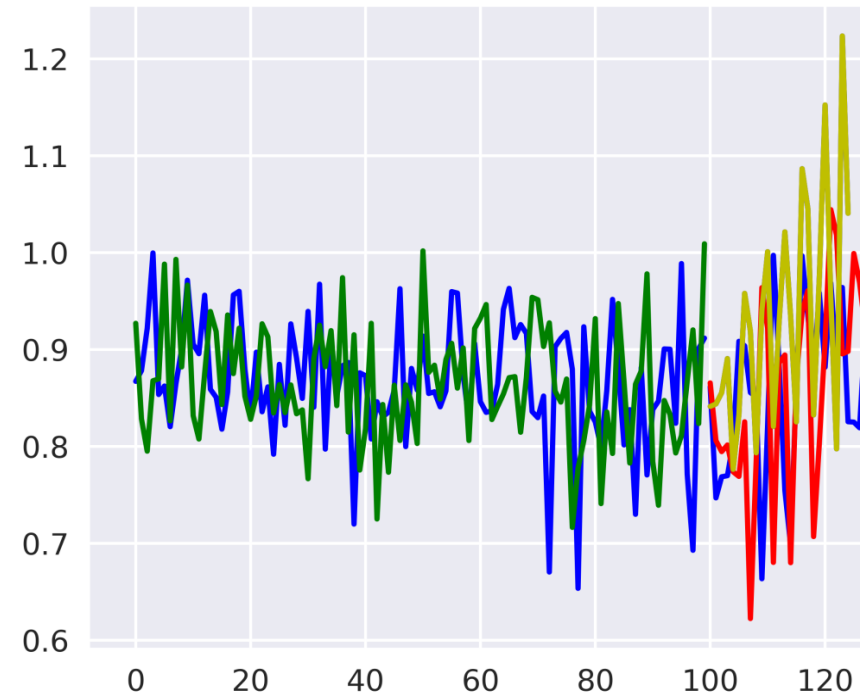
	Predict	Forecast
Mean absolute percentage error (%)		
Momentary current consumption	5.0599	4.5306
Momentary power consumption	6.0693	4.48156
Momentary energy consumption	3.1116	3.3868

01.07.2022 y. AGV with no load

Momentary current consuption



Battery cell voltage

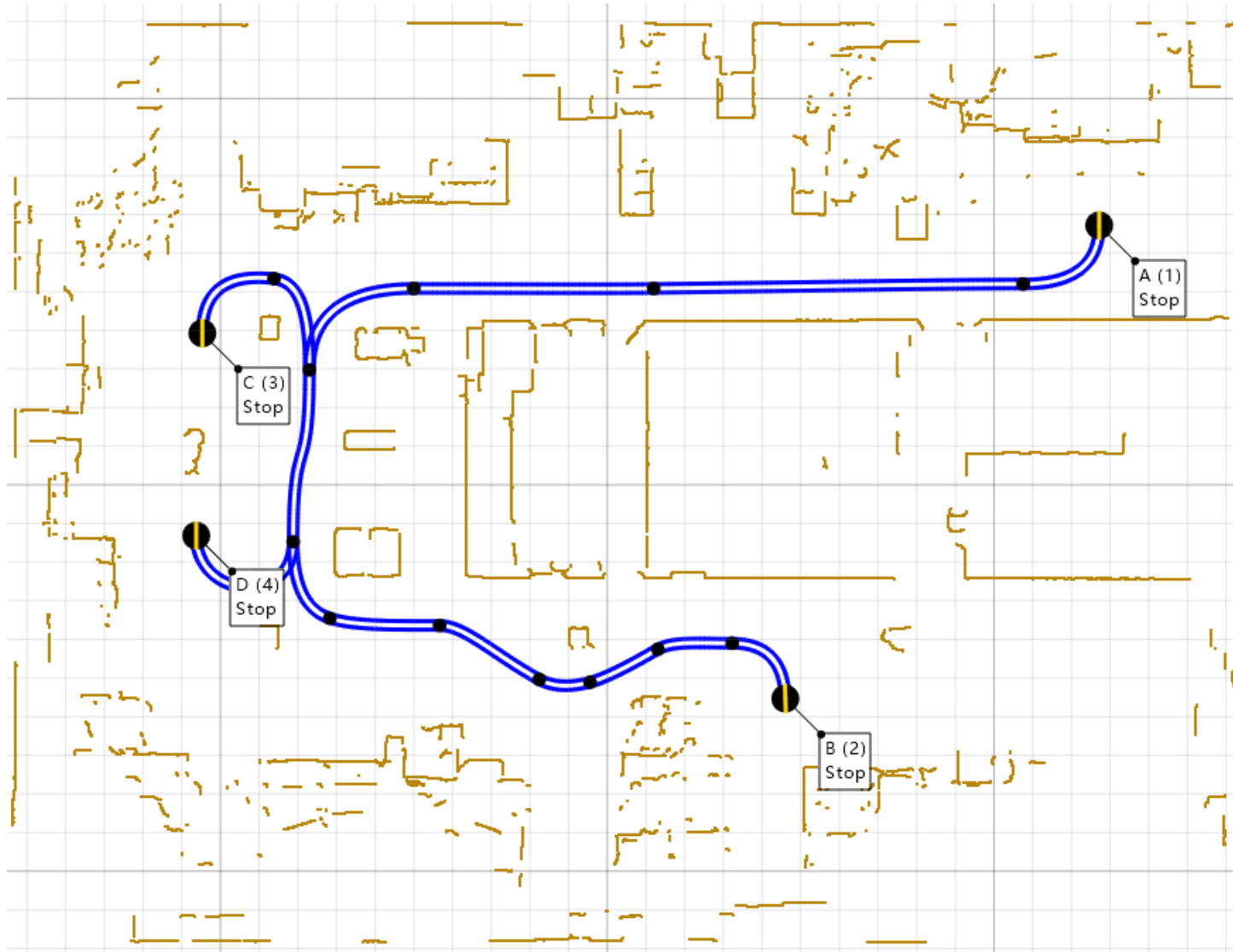


Mean absolute percentage error (%)	Predict	Forecast
Momentary current consumption	11.3120	14.1028
Momentary power consumption	8.8401	16.3657

Part 3. Battery voltage fall forecast

- Split data to the static and dynamic parameters sets for the ANN inputs and outputs
- Normalize all data [0,1]
- Build the ANN model
- ANN training and testing
- ANN battery voltage forecast
- Comparison the really measured battery voltage with the forecasts obtained based on the statistical, and the ANN methods

3.1. AGV pass A-> C-> D-> B



3.2 Static parameters for ANN inputs (22.06.2022 y.)

STATIC PARAMETERS = ['Segment', 'Samples count', 'Duration', 'Voltage delta']
 PREDICTED PARAMETERS = ['Start segment voltage']

	Segment	Samples count	Duration	Start segment voltage	Voltage delta
0	4.0	40.0	91.0	42890.0	40.0
1	7.0	14.0	13.0	42930.0	-50.0
2	4.0	1.0	0.0	42880.0	0.0
3	35.0	16.0	55.0	43070.0	0.0
4	31.0	4.0	5.0	43070.0	-30.0
...
178	31.0	3.0	3.0	42470.0	-10.0
179	45.0	10.0	9.0	42460.0	0.0
180	21.0	55.0	64.0	42460.0	0.0
181	22.0	50.0	59.0	42460.0	-20.0
182	46.0	9.0	9.0	42440.0	-10.0

183 rows × 5 columns

	Segment	Samples count	Duration	Voltage delta
162	11.0	4.083333	3.083333	-1.666667
163	35.0	6.923077	10.230769	-1.538462
164	31.0	4.000000	3.785714	-3.571429
165	19.0	10.666667	12.333333	0.000000
166	43.0	15.200000	19.000000	6.000000
167	40.0	12.600000	13.600000	-16.000000
168	16.0	8.666667	8.666667	-5.000000
169	28.0	4.153846	3.538462	-0.769231
170	32.0	5.000000	4.666667	-5.833333
171	8.0	3.750000	3.083333	3.333333
172	14.0	10.166667	10.166667	-3.333333
173	38.0	27.142857	46.714286	15.714286
174	37.0	17.285714	20.142857	-24.285714
175	13.0	9.333333	10.000000	3.333333
176	11.0	4.083333	3.083333	-1.666667
177	35.0	6.923077	10.230769	-1.538462
178	31.0	4.000000	3.785714	-3.571429
179	45.0	8.750000	8.750000	-5.000000
180	21.0	52.250000	69.500000	7.500000
181	22.0	44.500000	53.500000	-26.250000
182	46.0	9.125000	9.125000	0.000000

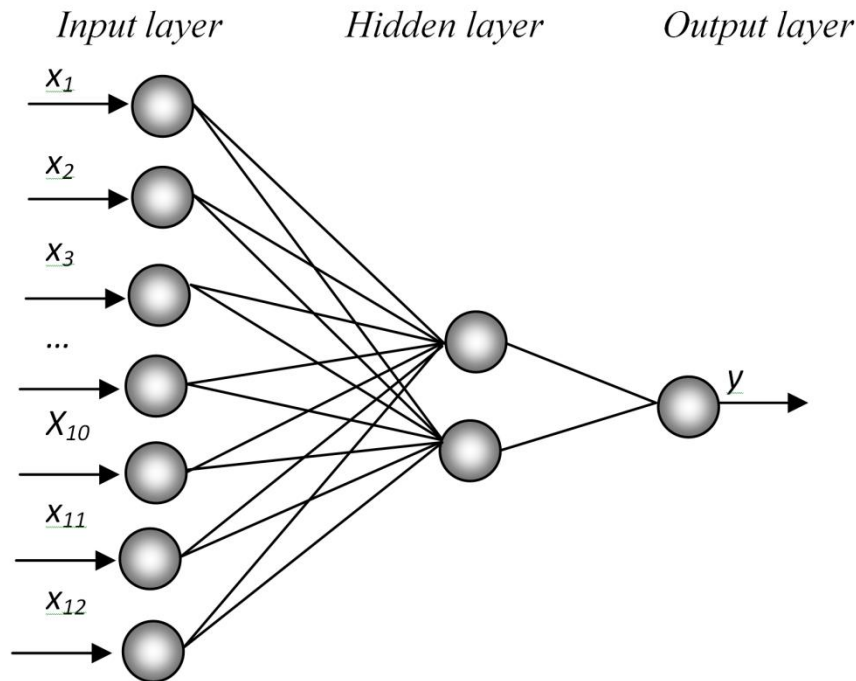
3.3. Normalize all data [0,1]

	Segment	Samples count	Duration	Start segment voltage	Voltage delta
0	0.000000	0.278571	0.164557	0.714286	0.833333
1	0.071429	0.092857	0.023508	0.777778	0.083333
2	0.000000	0.000000	0.000000	0.698413	0.500000
3	0.738095	0.107143	0.099458	1.000000	0.500000
4	0.642857	0.021429	0.009042	1.000000	0.250000
...
178	0.642857	0.014286	0.005425	0.047619	0.416667
179	0.976190	0.064286	0.016275	0.031746	0.500000
180	0.404762	0.385714	0.115732	0.031746	0.500000
181	0.428571	0.350000	0.106691	0.031746	0.333333
182	1.000000	0.057143	0.016275	0.000000	0.416667

183 rows × 5 columns

3.4. ANN model

The number of neurons



- Input layer - 12 neurons per input parameter,
- Hidden layer 2 neurons per output parameter
- Output layer -1 per output parameter

Input parameters when AGV enters the sector:

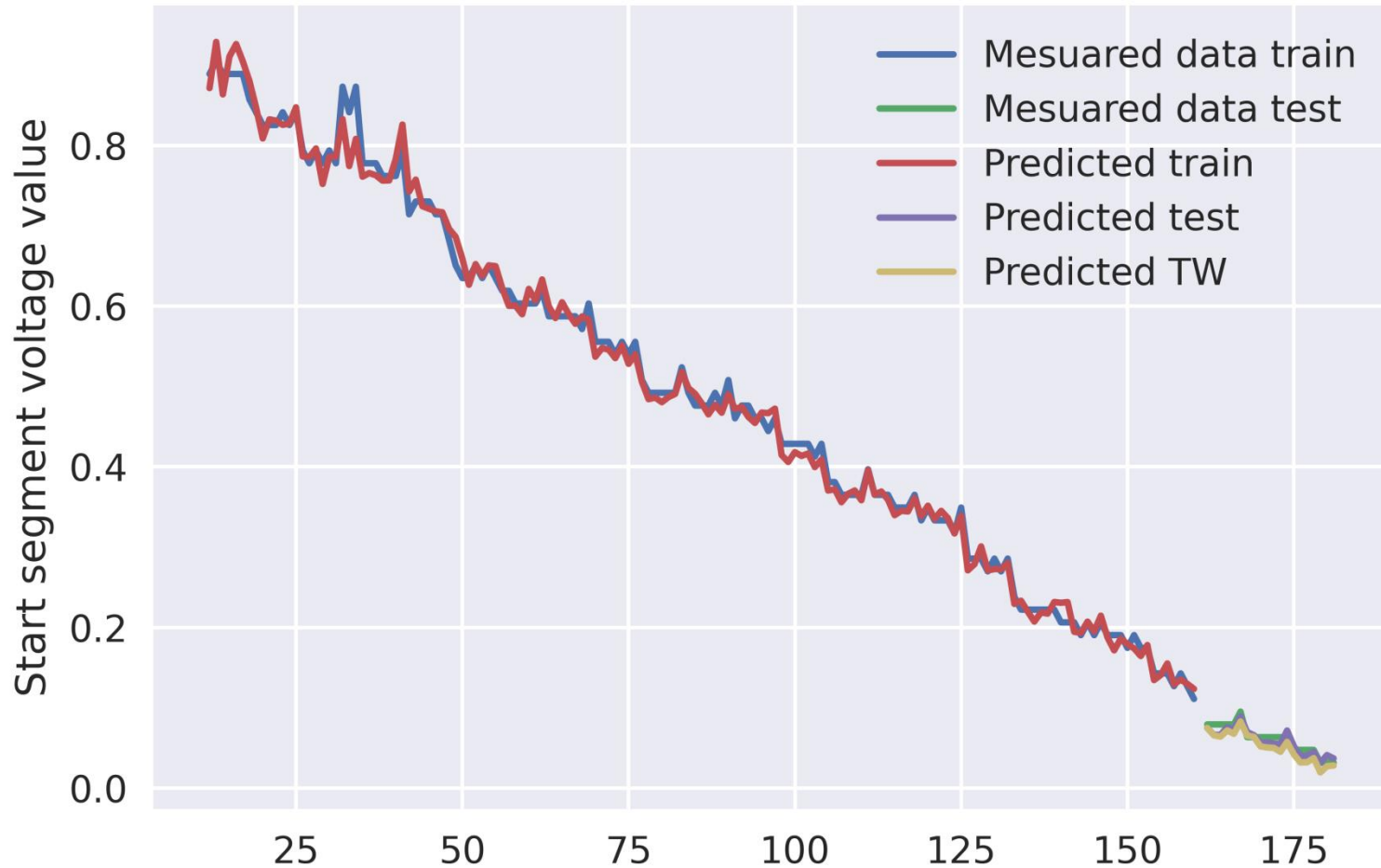
- Segment,
- Samples count,
- Duration,
- Voltage delta,
- Start segment voltage

Output parameter when AGV leaves the sector

- Start segment voltage

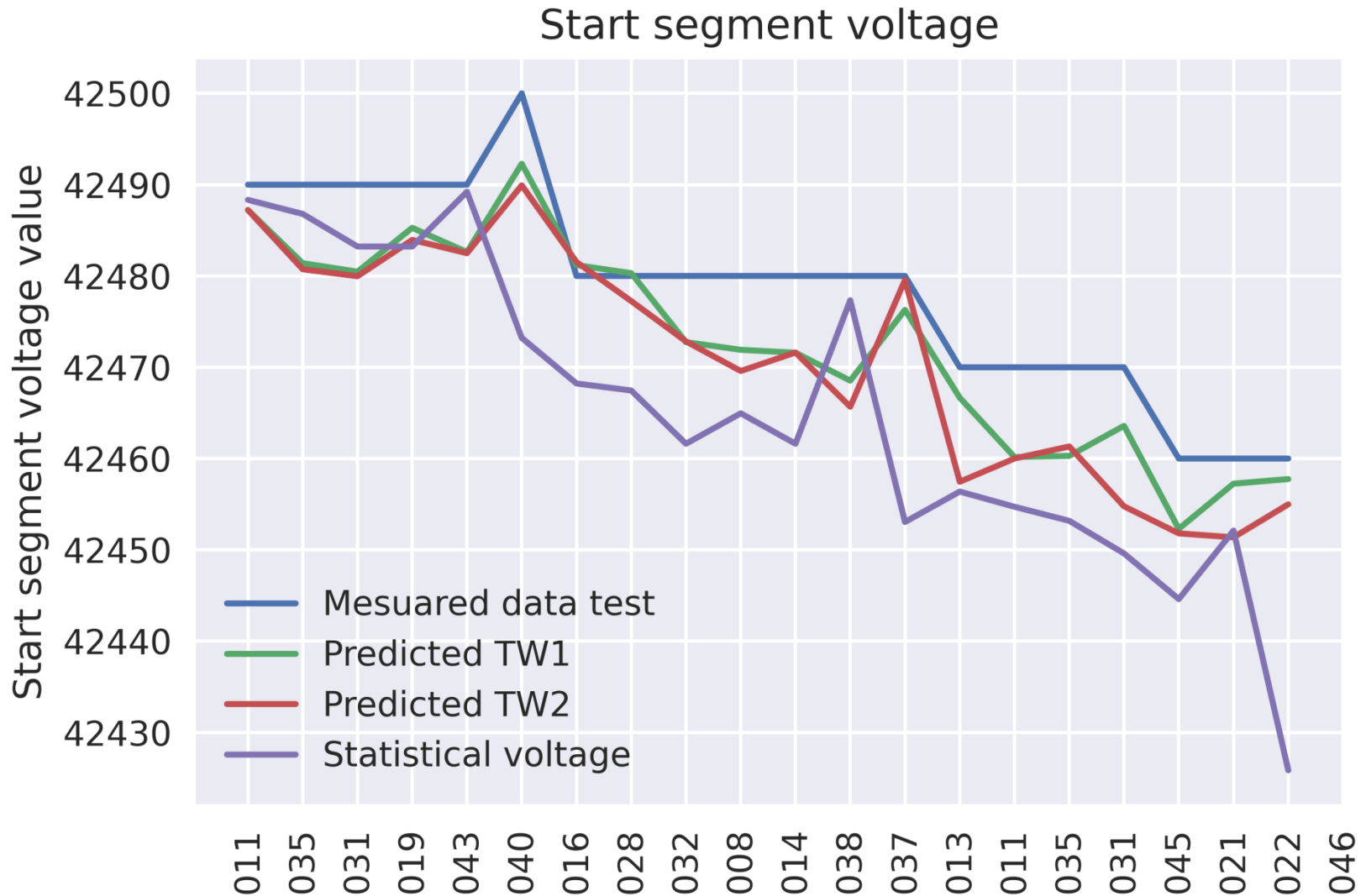
3.5. ANN training and testing

Start segment voltage



Learn mean absolute percentage error 2.9388 %;

3.6. ANN Forecast



3.7. Forecast Results Comparison

Path through the 21 segments	011 035 031 019 043 040 016 028 032 008 014 03...
Overall duration (sec)	326.986905
Battery voltage max fall (fact)	-38.0
Battery voltage max fall (ANN:TW1)	-42.382812
Battery voltage max fall (ANN:TW2)	-42.382812
Battery voltage max fall (stat)	-64.143773
Final battery voltage (fact)	22.0
Final battery voltage (ANN:TW1)	42457.75
Final battery voltage (ANN:TW2)	42454.988281
Final battery voltage (stat)	-26.25
MAPE (ANN:TW1) %	0.014653
RMS (ANN:TW1) %	0.003573
MAPE (ANN:TW2) %	0.01867
RMS (ANN:TW2) %	0.004514
MAPE (stat) %	0.032447
RMS (stat) %	0.003573

Results

Data mining phase:

- using the correlation analysis the most valuable parameters for the AGV power consumption are determined;
- algorithms for the insufficient data padding and the spontaneous data peaks allocation and fixing are developed;
- methods for the data normalization, renormalization, and denormalization are designed;

Battery discharge prediction:

- two “multiparameter ANN in the time-window shift mode” - based approaches are proposed:
 1. having the diagnostic parameters changes history the problem of their behavior forecasting for the given future time-period is solved;
 2. (we developed the new approach) having the per segment averaged diagnostic parameters changes history, the battery cell voltage forecast problem is solved when the following sequence of the AGV path segments is given;
- the optimal ANN-models parameters were determined in an experimental way
- simple battery cell voltage prediction algorithm, based on the statistically averaged data, were used to compare the results.

Conclusions

- In the 1st approach, we obtained good enough results in the forecasting the diagnostic parameters behavior for the next 25mins, having the 100mins of the historical data
- In the 2nd approach, we obtained good enough results in the forecasting the Battery cell voltage after AGV pass the path of 21 following segments, having the averaged historical data for the previous 150 segments path;
- Compared the ANN based predictions results to the real measured data (on the ANN-test data set) and to the Statistical-based forecast results via the visual charts comparison and via the RMSE – errors calculations, and compared the calculation time: The ANN-based forecasts are more accurate than the statistical-one, but needs significantly more time for calculations.

Further research

1. Extend the parameters set is used to train and test ANN
2. Developed the measurement principles and approaches to create the training data sets and perform the necessary measurements
3. Investigate using the non-iterative ANNs to reduce the training and prediction time
4. Created software code optimization to work in real conditions on AGV.