

MATLAB EXPO

Development of abnormal detection system for hydrogen refueling station using MATLAB

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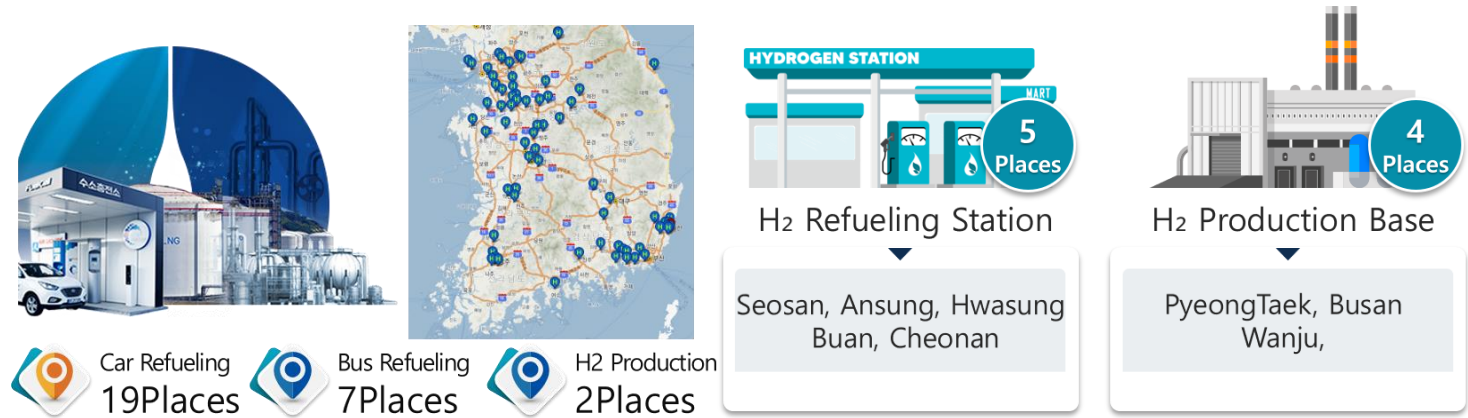


Contents

- Introduction to our Business
- Business Characteristics
- Technical Challenges for the Data Pipeline
 - Historical data access
 - Communication between the PI AF and MPS
- Technical Challenges for Application
 - Anomaly detection; Time-series multivariate with multi-mode

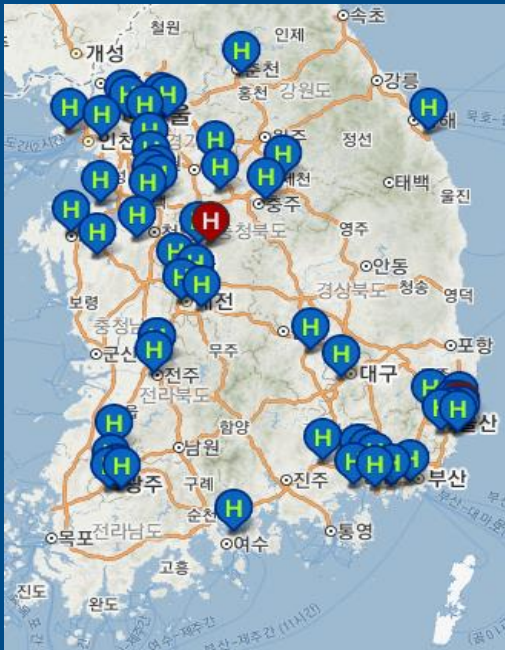
Introduction to our Business

- Hydrogen Infrastructure Construction
- Hydrogen Infrastructure Operation
- Hydrogen Infrastructure Maintenance



Maintenance Strategies for Hydrogen Refueling Station

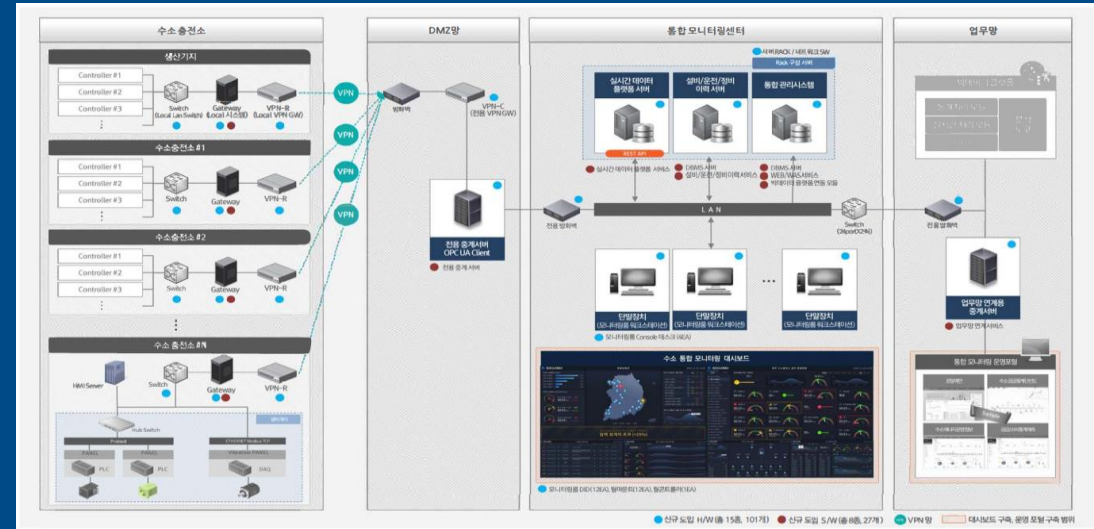
Business Characteristics



Wide area >> experts

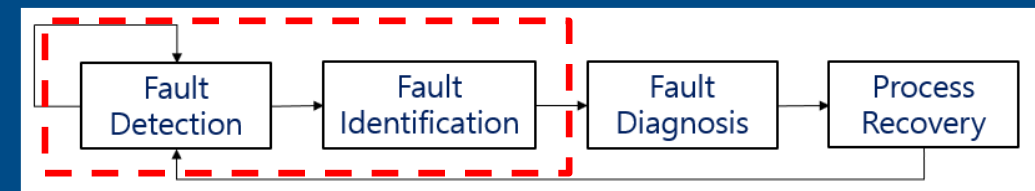


Architecture of the Data Pipeline



Real-time data gathering and monitoring

Application for Decision Support

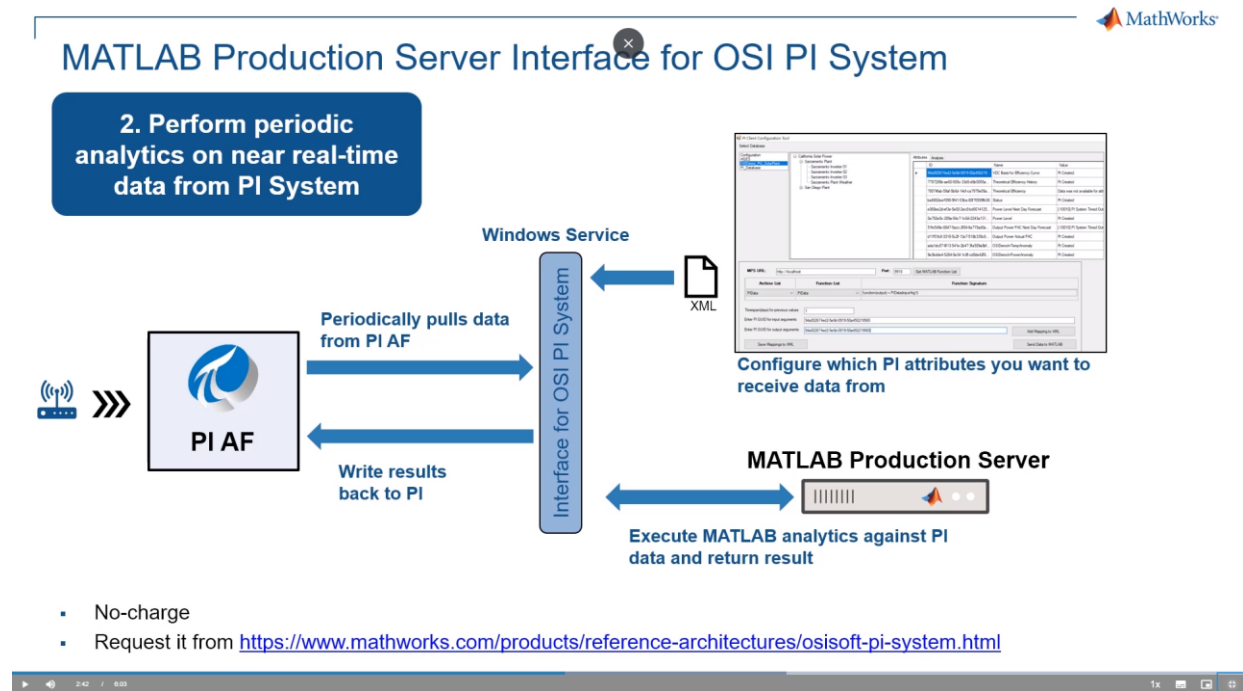


Anomaly detection and Identification

Technical Challenges for the Data Pipeline

Perform periodic analytics on near real-time

- OSI PI System / PI Asset Framework (PI AF)
 - Historical data access
 - Communication between the PI AF and MPS
- MATLAB Production Server
 - Data analysis
- Window Service / XML
 - MATLAB Production Server interface for PI



Historical data access

Get Started Accessing Data from a PI Server

- Create Client and Connect to Server

```
client = piclient("10.10.10.200");
```

- List All Tags

```
Target_Tags = tags(client, Name= "*guesan*press")
```

Target_Tags = 1x1 table

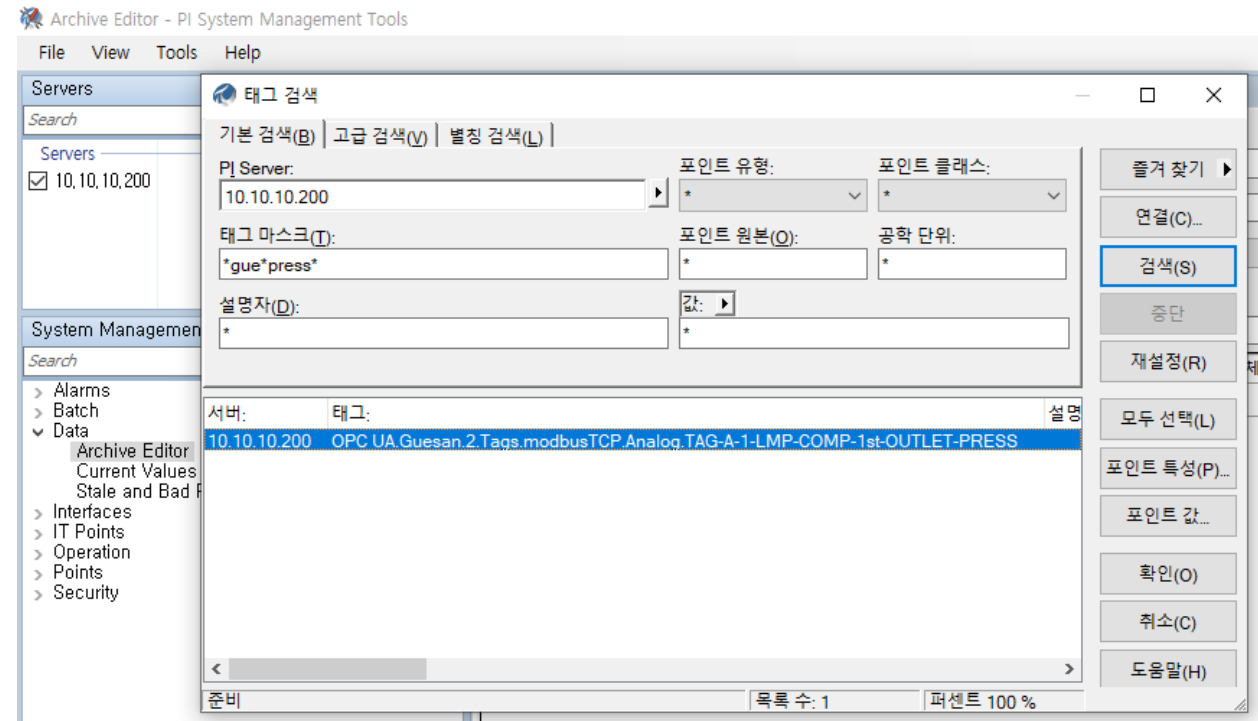
	Tags
1	"OPC UA.Guesan.2.Tags.modbusTCP.Analog.TAG-A-1-LMP-COMP-1st-OUTLET-PRESS"

- Read Latest Value of Tag

```
MP_1st_PT = read(client, Target_Tags.Tags(1))
```

MP_1st_PT = 1x3 timetable

	Time	Tag	Value	Status
1	22-5월-2023 08:01:52	"OPC UA.Guesan.2.Tags.modbusTCP.Analog.TAG-A-1-LMP-COMP-1st-OUTLET-PRESS"	31	Good



Historical data access

Interpolate Irregular Timetable Data

- Specify Time Step and interpolation data

```
dt = seconds(1);
PT1 = retime(MP_1st_PT_TwoDays,'regular','linear','TimeStep',dt);
```

- Synchronize Timetable Variables

```
snapshot = synchronize(PT1,PT2);
```

Snapshot

	Time	1	2	3	4	5	6	7	8
	2022-08-18 07:00:00	34	23	34	22	0	24	34	0
	2022-08-18 07:00:01	34	23	34	22	0	24	34	0
	2022-08-18 07:00:02	34	23	34	22	0	24	34	0
	2022-08-18 07:00:03	34	23	34	22	0	24	34	0
	2022-08-18 07:00:04	34	23	34	22	0	24	34	0
	2022-08-18 07:00:05	34	23	34	22	0	24	34	0
	2022-08-18 07:00:06	34	23	34	22	0	24	34	0
	2022-08-18 07:00:07	34	23	34	22	0	24	34	0
	2022-08-18 07:00:08	34	23	34	22	0	24	34	0
	2022-08-18 07:00:09	34	23	34	22	0	24	34	0
	2022-08-18 07:00:10	34	23	34	22	0	24	34	0
	2022-08-18 07:00:11	34	23	34	23	0	24	34	0
	2022-08-18 07:00:13	34	23	34	23	0	24	34	0
	2022-08-18 07:00:14	34	23	34	23	0	24	34	0
	2022-08-18 07:00:15	34	23	34	23	0	24	34	0
	2022-08-18 07:00:16	34	23	34	23	0	24	34	0
	2022-08-18 07:00:17	34	23	34	23	0	24	34	0
	2022-08-18 07:00:18	34	23	34	23	0	24	34	0
	2022-08-18 07:00:19	34	23	34	23	0	24	34	0
	2022-08-18 07:00:20	34	23	34	23	0	24	34	0



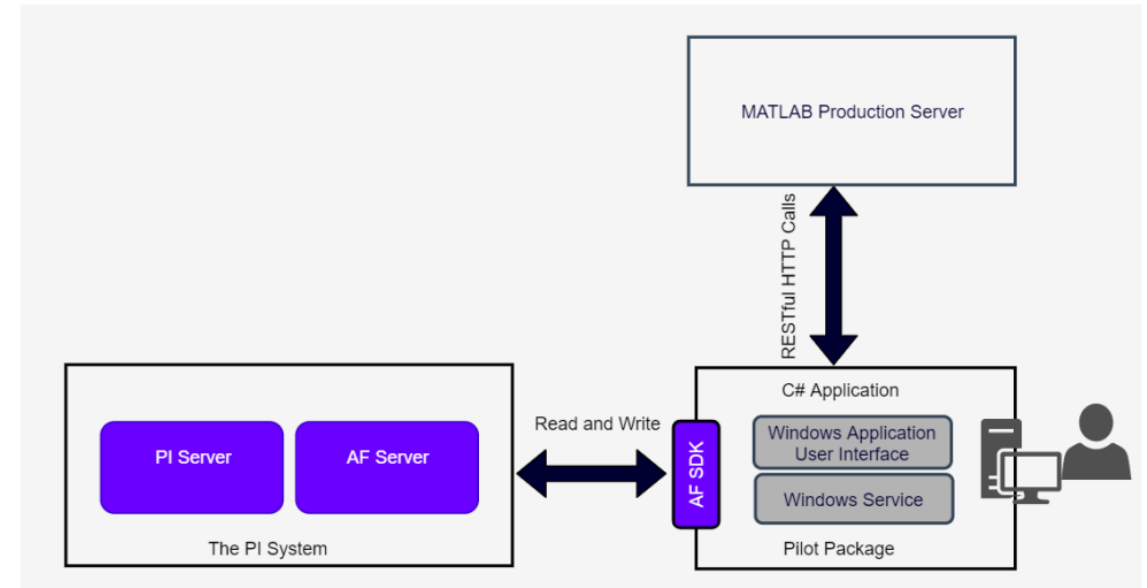
**Data analysis &
Development**

Perform periodic analytics on near real-time

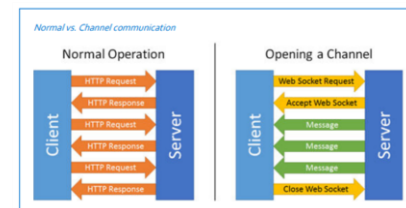
Communication between the PI AF and MPS

- MATLAB Production Server Compiler
 - Project package
- PI AF
 - Create/Connect database
- XML file description
 - Configuration data mapping
- Window Service
 - Starting the service

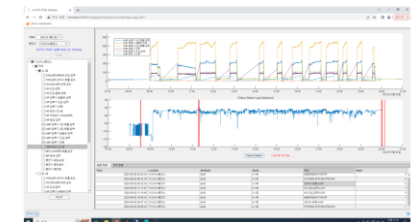
Architecture of the integration



PI Web API



Web Application



Perform periodic analytics on near real-time

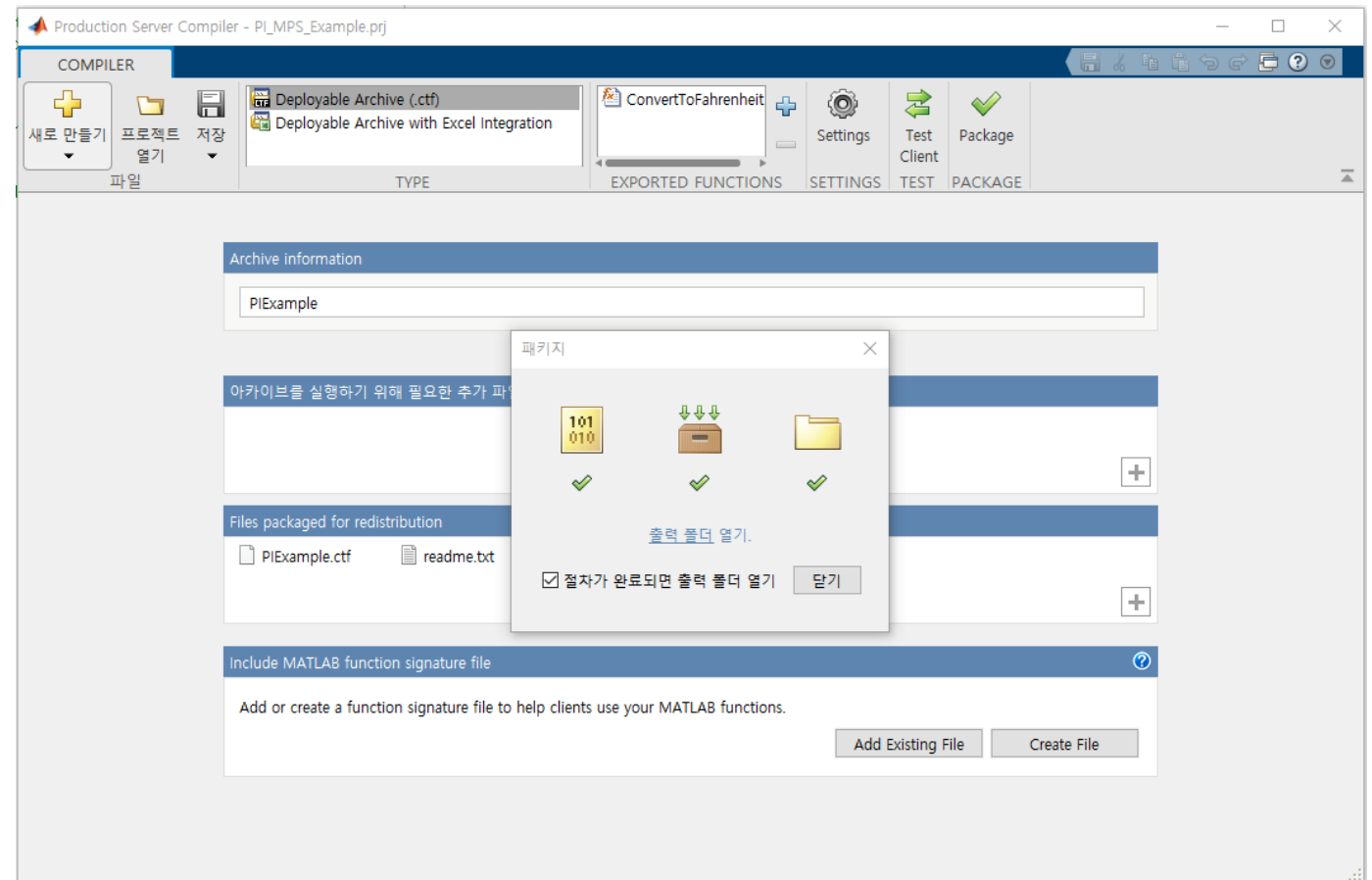
Production Sever Project package

```
function [fTemp1,fTemp2] = ConvertToFahrenheit(cTemp1,cTemp2)

% ConvertToFahrenheit - This MATLAB function accepts temperature in Celsius
% and converts to Fahrenheit
% Copyright 2020 MathWorks
disp(cTemp1)
fTemp1 = cTemp1(1).Value * (9/5) + 32;
fTemp2 = cTemp2(1).Value * (9/5) + 32;
end

// Function Signatures
// To optionally specify argument types and/or sizes, search for "type"
// and insert the appropriate specifiers inside the brackets. For example:
//
// "type": ["double", "size=1,1"]
//
// To modify function or parameter help text, search for "purpose" and edit
// the values.
//
// JSON-formatted text below this line.
{
  "ConvertToFahrenheit": {
    "inputs": [
      {
        "name": "cTemp1",
        "type": [],
        "purpose": ""
      },
      {
        "name": "cTemp2",
        "type": [],
        "purpose": ""
      }
    ],
    "outputs": [

```



Perform periodic analytics on near real-time

Create/Connect database

The screenshot displays the PI System Explorer interface. The left pane shows a tree view of elements under the root 'Elements'. The right pane shows the configuration for 'Element2'.

Elements Tree View:

- Elements
 - OPC UA
 - 강서충전소
 - 과산개미충전소
 - Element1
 - modbusTCP
 - OPC UA
 - SCADA
 - 부안수소충전소
 - 서산수소충전소
 - 성남E1수소충전소
 - 안성아트센터수소충전소
 - 양산차고지수소충전소
 - 전주삼천수소충전소
 - 제천삼보수소충전소
 - 진천충전소
 - 전안버스수소충전소
 - 청주가로수수소충전소
 - 청주문의수소충전소
 - 춘천동내수소충전소
 - 충주버스수소충전소
 - 평택버스충전소
 - 화성체육시설수소충전소
- Plant1
 - Element1
 - Element2
 - Element3
- Element Searches

Element2 Configuration:

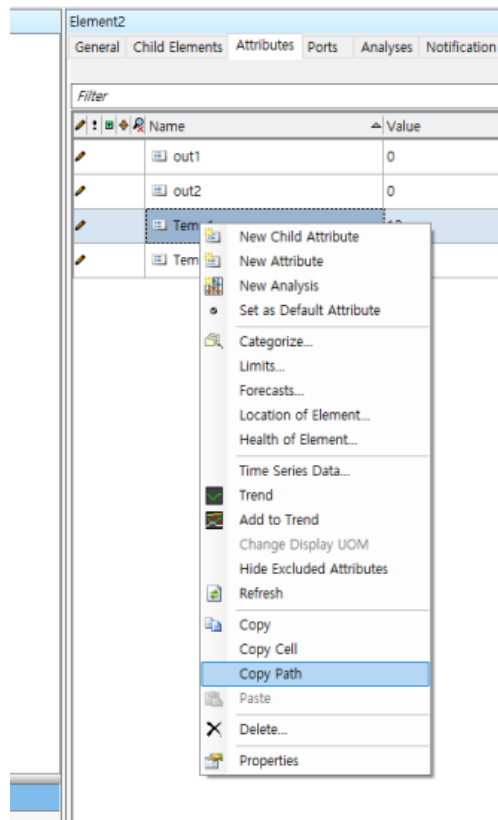
General | Child Elements | Attributes | Ports | Analyses | Notification Rules | Version

Filter

Name	Value
out1	0
out2	0
Temp1	12
Temp2	12

Perform periodic analytics on near real-time

Configuration data mapping



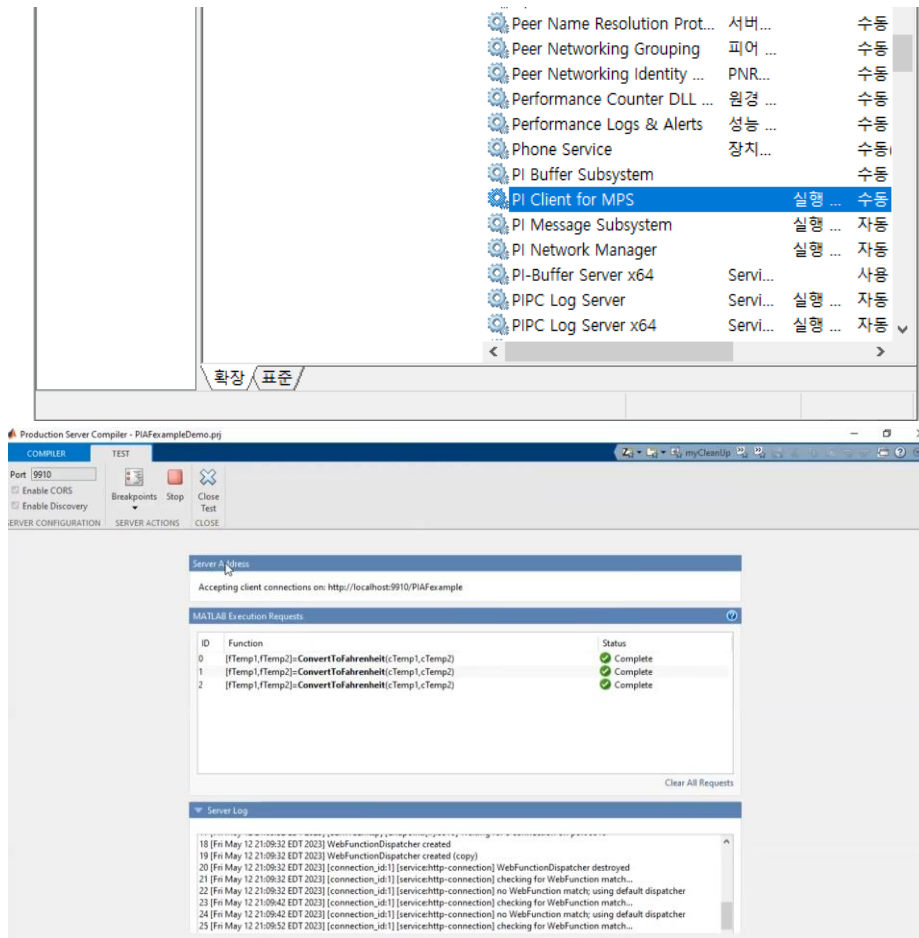
```

<PIClientconfiguration>
  <MPSURL>http://localhost:9910</MPSURL>
  <Mappings>
    <Mapping>
      <Archive name="PIExample">
        <MATLABFunction name="ConvertToFahrenheit">
          <InputArgument>
            <TimeinMins>2</TimeinMins>
            <PIInput>%%HMCPISVR%%HMCP|AFWP|ant1WE|ement1WE|ement2|Temp1</PIInput>
          </InputArgument>
          <InputArgument>
            <TimeinMins>2</TimeinMins>
            <PIInput>%%HMCPISVR%%HMCP|AFWP|ant1WE|ement1WE|ement2|Temp2</PIInput>
          </InputArgument>
          <OutputArgument>
            <PIOutput>%%HMCPISVR%%HMCP|AFWP|ant1WE|ement1WE|ement2|out1</PIOutput>
          </OutputArgument>
          <OutputArgument>
            <PIOutput>%%HMCPISVR%%HMCP|AFWP|ant1WE|ement1WE|ement2|out2</PIOutput>
          </OutputArgument>
        </MATLABFunction>
      </Archive>
    </Mapping>
  </Mappings>
</PIClientconfiguration>

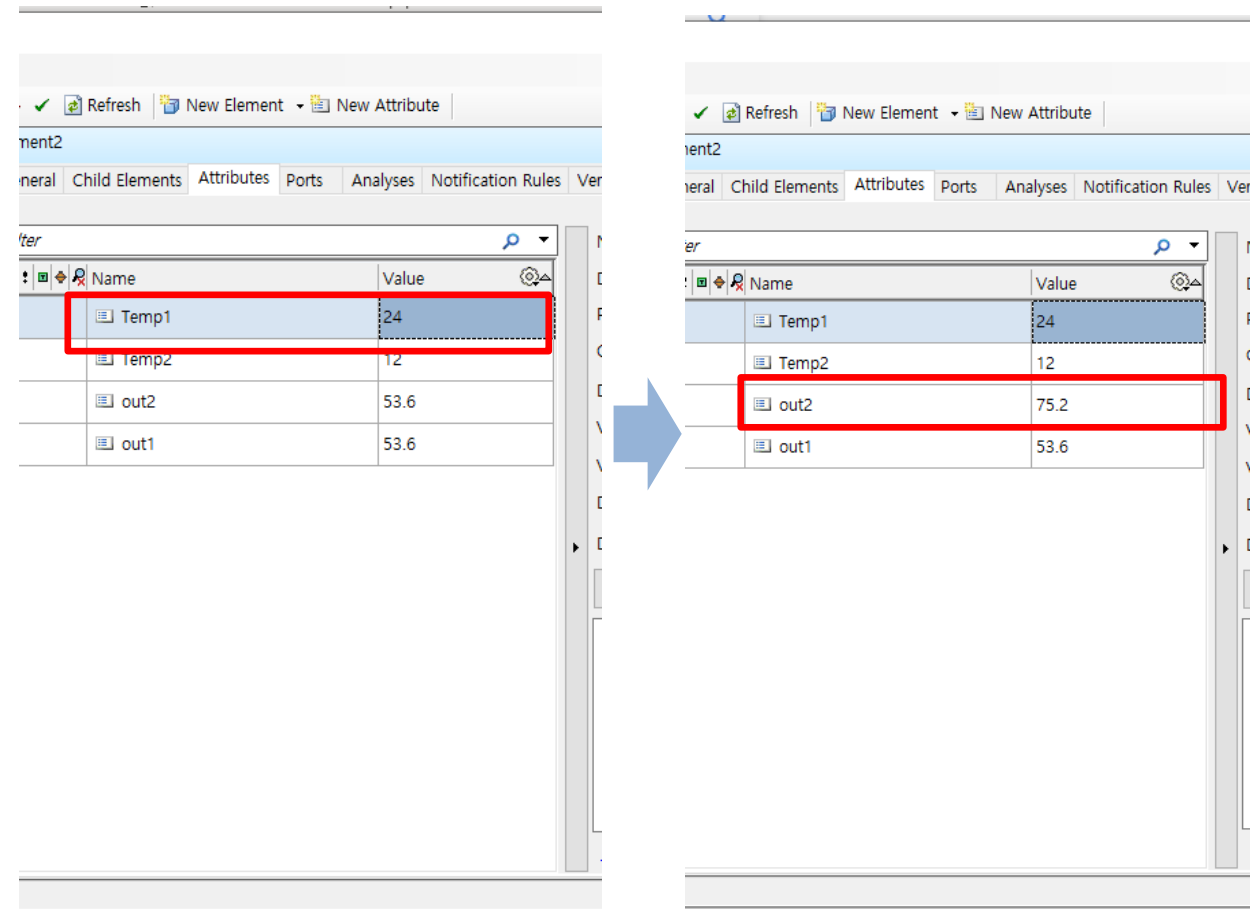
```

Perform periodic analytics on near real-time

Starting the service



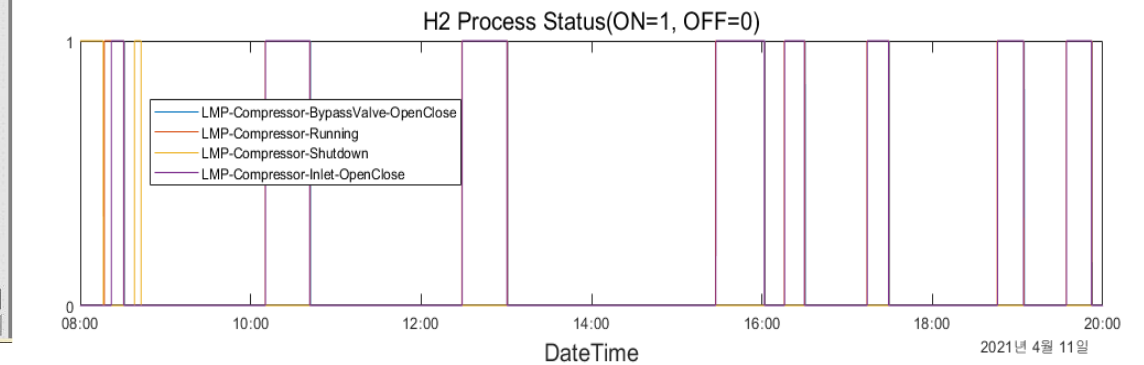
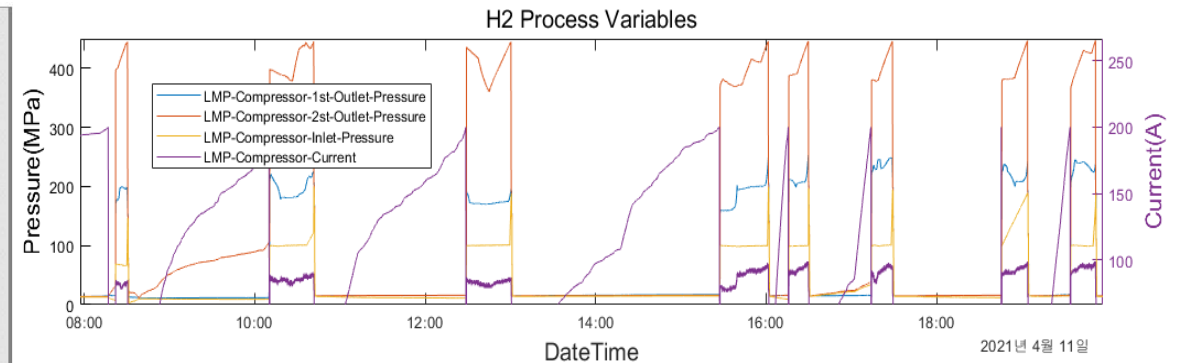
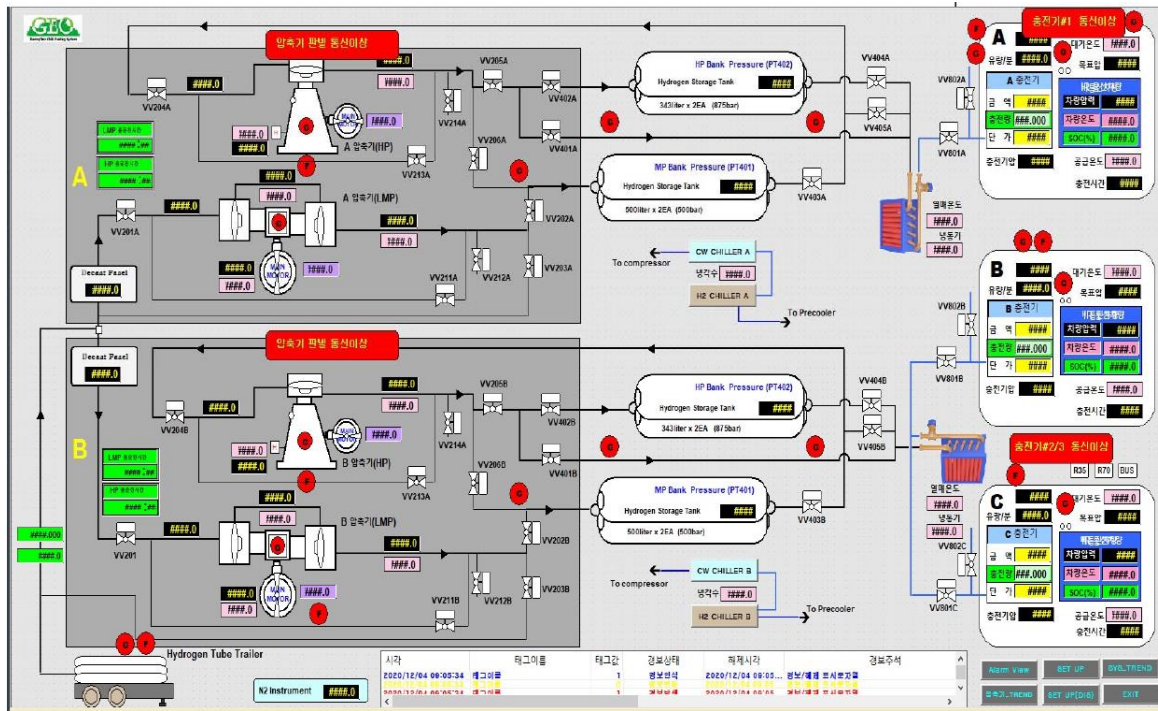
Communication between the PI AF and MPS



Technical Challenges for Application

Anomaly detection

- Time-series multivariate with multi-mode



HMM-GMM

Gaussian Mixture Model(GMM)

$$p(x) = \sum_{m=1}^M w_m p(x|N(\mu_m; \sigma_m)), \sum w_i = 1$$

$$\theta = (w_m, \mu_m, \sigma_m)$$

Hidden Markov Model(HMM)

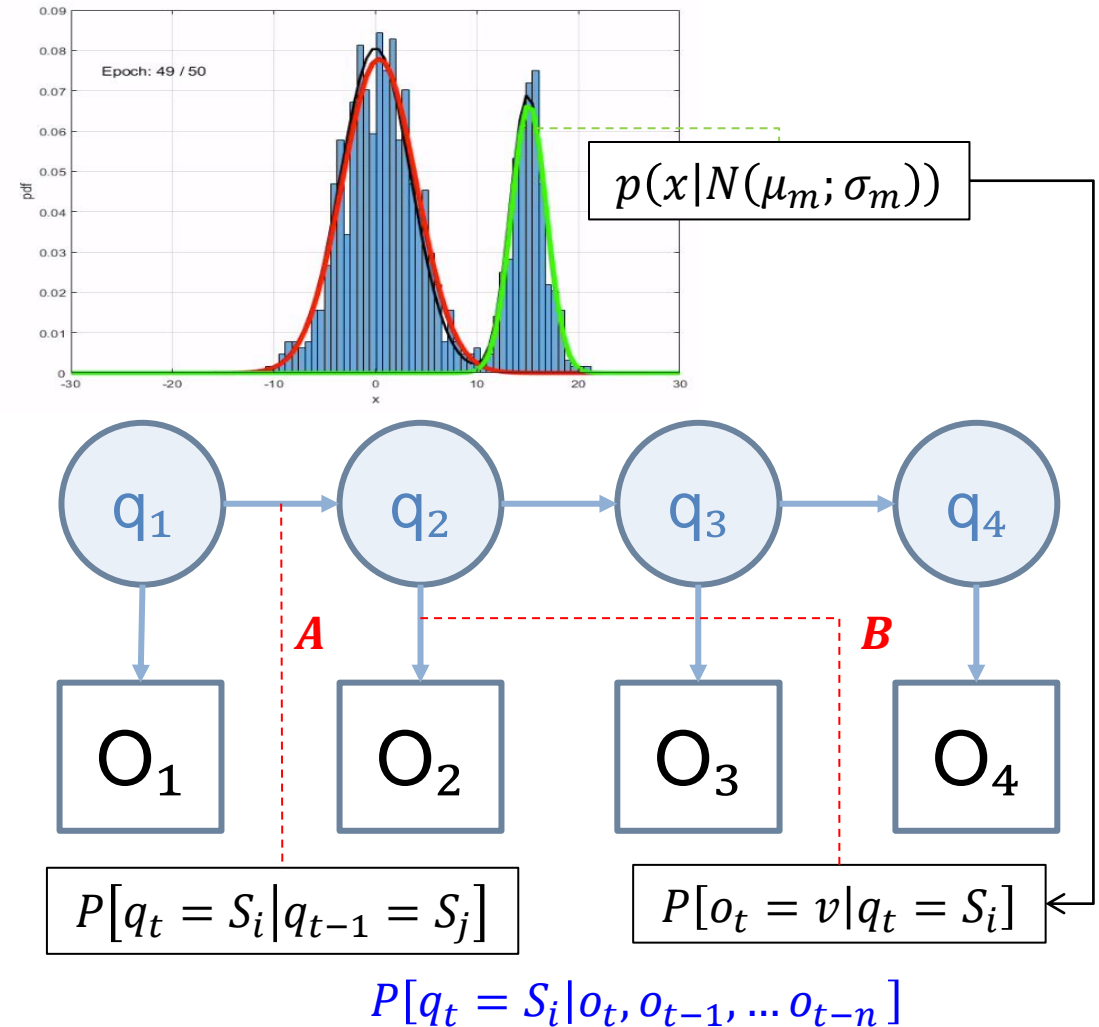
$$A = \{a_{ij}\} = P[q_{t+1} = S_i | q_t = S_j], 1 \leq i, j \leq N$$

$$B = \{b_{ij}\} = P[o_t = v_i | q_t = S_j], 1 \leq j \leq N, 1 \leq k \leq m$$

$$\pi_i = P[q_1 = S_i], 1 \leq i \leq N$$

$$\lambda = (A, B, \pi)$$

GMM - HMM



Model Training and test

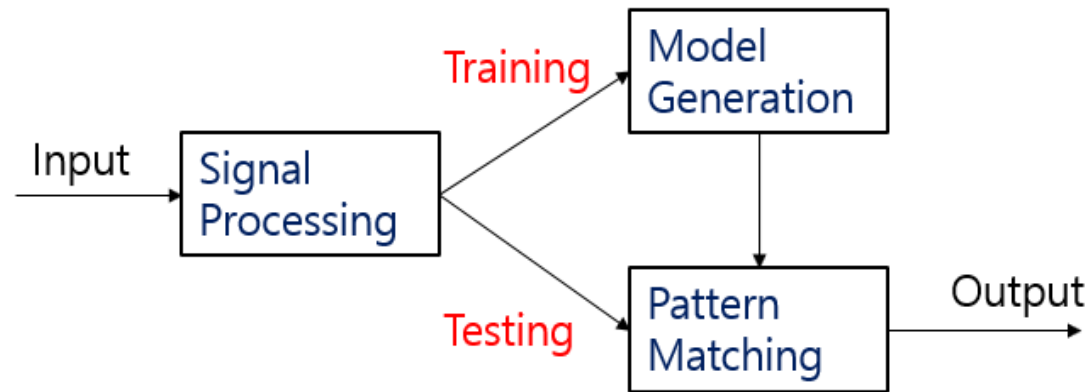
TABLE I. VARIABLES LIST FROM HYDROGEN REFUELING STATION

Field	DATA	TAG Name
Seosan hydrogen refueling station	STS	COOLING WATER CHILLER RUN H2 CHILLER RUN LMP COMP RUNNING OIL TANK HEATER RUN LMP COMP. COMMON SHUTDOWN HP COMP LOAD HP COMP. HEATER ON HP COMP. COMMON SHUTDOWN EQUIPMENT SHUTDOWN LMP COMP INLET ACT VALVE LMP COMP OUTLET ACT VALVE LMP COMP BYPASS ACT VALVE HP COMP INLET ACT VALVE HP COMP OUTLET ACT VALVE HP COMP BYPASS ACT VALVE DIRECT FILL ACT VALVE HP COMP. LEFT LIMIT ON HP COMP. RIGHT LIMIT ON MP COMP. LEFT LIMIT ON MP COMP. RIGHT LIMIT ON
	PV	H2 INLET MASS FLOW INSTRUMENT N2 PRESS INSTRUMENT N2 PRESS LOW LMP COMP INLET PT LMP COMP 1ST OUT PT LMP COMP 2ND OUT PT LMP COMP LUBE OIL PT LMP COMP 1ST OUTLET TEMP LMP COMP 2ND OUTLET TEMP LMP COMP LUBE OIL TEMP LMP COMP CUREENT PV HP COMP INLET PT HP COMP OUTLET PT HP COMP LUBE OIL PT HP COMP OUTLET TEMP HP COMP LUBE OIL TEMP HP COMP CUREENT PV H2 INLET PRESS MID PRESS STORAGE TANK PRESS HI PRESS STORAGE TANK PRESS MP COMP COOLER OUTLET TEMP H2 PRE COOLER H2 INLET TEMP H2 PRE COOLER H2 OUTLET TEMP H2 CHILLER COOLER LIQUID TEMP CHILLER.CW.TEMP1 CHILLER.CW.TEMP1_B CHILLER.BRAIN_INLET_T CHILLER.BRAIN_OUTLET_T CHILLER.BRAIN_INLET_T2 CHILLER.BRAIN_OUTLET_T2

- allocating operation mode using state variables
 - Mode := State
 - Tag data := Observation

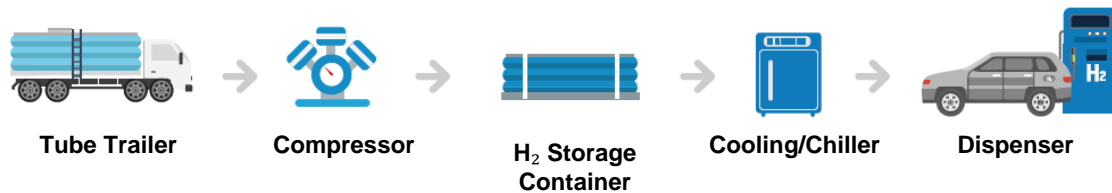
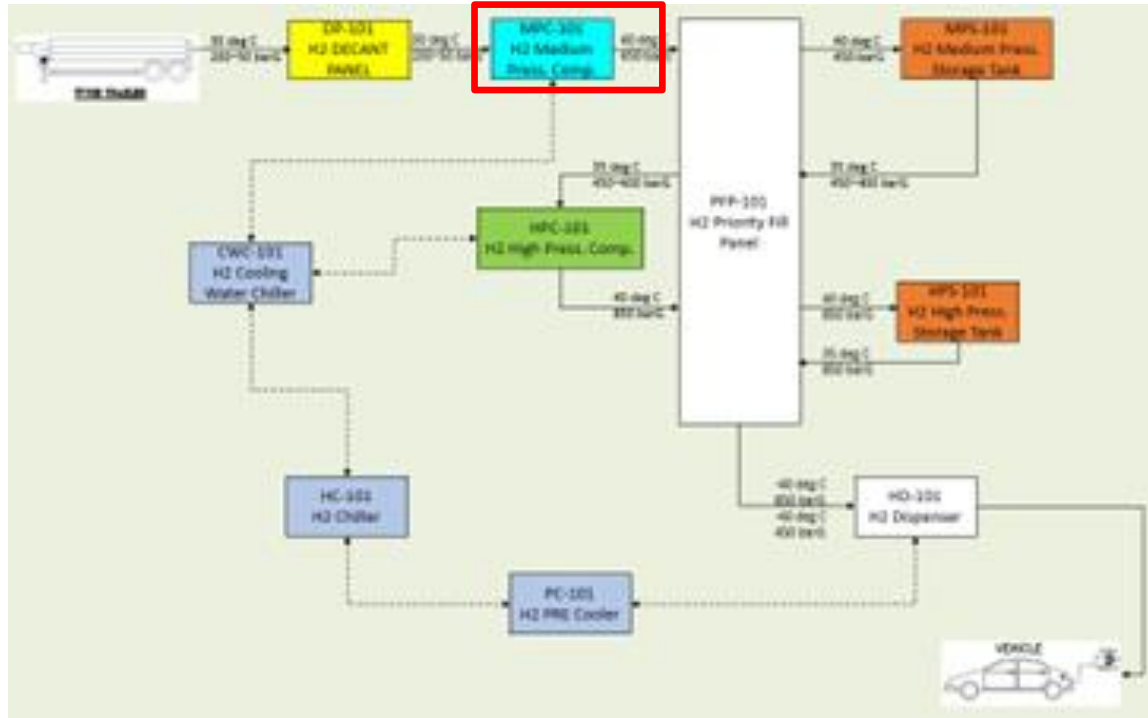
Valve 1	System 2	Operation Mode No.	PT	TT	IT
Open	ON	1	23	56	1
Open	OFF	2	24	55	1
Closed	ON	3	25	55	2
Closed	OFF	4	24	56	1

- Training HMM-GMM model



Training → Extract $\lambda = (A, \pi_i, w_m, \mu_m, \sigma_m)$
Testing the given $o_t, o_{t-1} \dots o_{t-n}$ → Evaluate $\text{Log}(P[o_t = v | o_{t-1}, \dots o_{t-n}])$

Divide the category – Domain insight



27×1 cell 배열

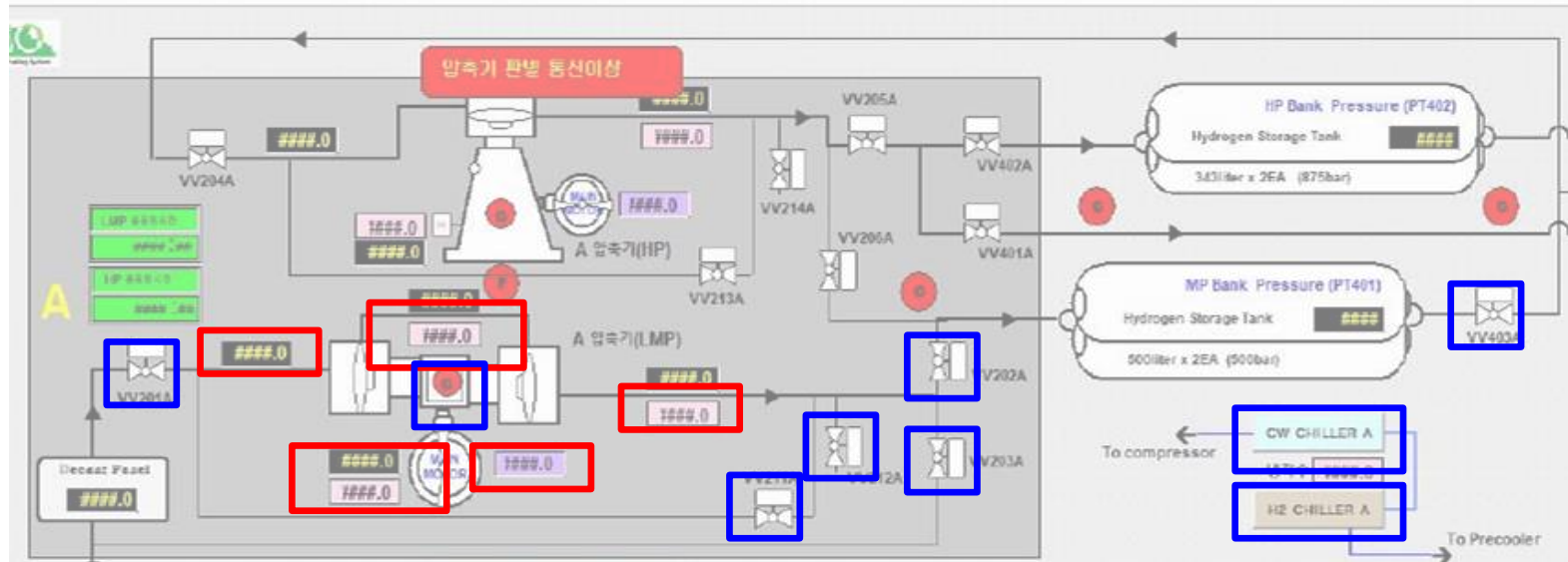
```
{'STS-A-1호-C-WATER-&-CHILLER-RUN'      }
{'STS-A-1호-H2-CHILLER-RUN'            }
{'STS-A-1호-HP-압축기-BYPASS-XV-V_V-OPEN_CLOSE'}
{'STS-A-1호-HP-압축기-LEFT-XV-LIMIT-ON'  }
{'STS-A-1호-HP-압축기-RIGHT-XV-LIMIT-ON' }
{'STS-A-1호-HP-압축기-RUNNING'          }
{'STS-A-1호-HP-압축기-SHUTDOWN'         }
{'STS-A-1호-HP-압축기-인입-XV-V_V-OPEN_CLOSE'}
{'STS-A-1호-HP-압축기-토출-XV-V_V-OPEN_CLOSE'}
{'STS-A-1호-HP-압축기-히터-ON'          }
{'STS-A-1호-LMP-압축기-BYPASS-XV-V_V-OPEN_CLOSE'}
{'STS-A-1호-LMP-압축기-RUNNING'         }
{'STS-A-1호-LMP-압축기-SHUTDOWN'        }
{'STS-A-1호-LMP-압축기-인입-XV-V_V-OPEN_CLOSE'}
{'STS-A-1호-LMP-압축기-토출-XV-V_V-OPEN_CLOSE'}
{'STS-A-1호-LMP-오일탱크-히터-RUN'      }
{'STS-A-1호-LP-압축기-LEFT-XV-LIMIT-ON'  }
{'STS-A-1호-LP-압축기-RIGHT-XV-LIMIT-ON' }
{'STS-A-1호-MP-압축기-LEFT-XV-LIMIT-ON'  }
{'STS-A-1호-MP-압축기-RIGHT-XV-LIMIT-ON' }
{'STS-A-1호-전체-SHUTDOWN'              }
{'STS-A-1호-직공급-XV-V_V-OPEN_CLOSE'    }
{'STS-A-1호-충전기-MAIN-V_V'            }
{'STS-A-1호-충전기-VENT-V_V'            }
{'STS-A-1호-충전기-충전-HIGH-V_V'       }
{'STS-A-1호-충전기-충전-MID-V_V'        }
{'STS-A-1호-충전기-충전시작'            }
```



11×1 cell 배열

```
{'STS-A-1호-C-WATER-&-CHILLER-RUN'      }
{'STS-A-1호-H2-CHILLER-RUN'            }
{'STS-A-1호-HP-압축기-RIGHT-XV-LIMIT-ON' }
{'STS-A-1호-LMP-압축기-BYPASS-XV-V_V-OPEN_CLOSE'}
{'STS-A-1호-LMP-압축기-RUNNING'         }
{'STS-A-1호-LMP-압축기-SHUTDOWN'        }
{'STS-A-1호-LMP-압축기-인입-XV-V_V-OPEN_CLOSE'}
{'STS-A-1호-LMP-압축기-토출-XV-V_V-OPEN_CLOSE'}
{'STS-A-1호-MP-압축기-LEFT-XV-LIMIT-ON'  }
{'STS-A-1호-MP-압축기-RIGHT-XV-LIMIT-ON' }
{'STS-A-1호-전체-SHUTDOWN'              }
```


Define target and modes – Domain insight



11x1 cell 배열

```
{'STS-A-1호-C-WATER-&-CHILLER-RUN' }
{'STS-A-1호-H2-CHILLER-RUN' }
{'STS-A-1호-HP-압축기-RIGHT-XV-LIMIT-ON' }
{'STS-A-1호-LMP-압축기-BYPASS-XV-V_V-OPEN_CLOSE' }
{'STS-A-1호-LMP-압축기-RUNNING' }
{'STS-A-1호-LMP-압축기-SHUTDOWN' }
{'STS-A-1호-LMP-압축기-인입-XV-V_V-OPEN_CLOSE' }
{'STS-A-1호-LMP-압축기-토출-XV-V_V-OPEN_CLOSE' }
{'STS-A-1호-MP-압축기-LEFT-XV-LIMIT-ON' }
{'STS-A-1호-MP-압축기-RIGHT-XV-LIMIT-ON' }
{'STS-A-1호-전체-SHUTDOWN' }
```



4x1 cell 배열

```
{'STS-A-1호-HP-압축기-RIGHT-XV-LIMIT-ON' }
{'STS-A-1호-LMP-압축기-BYPASS-XV-V_V-OPEN_CLOSE' }
{'STS-A-1호-LMP-압축기-인입-XV-V_V-OPEN_CLOSE' }
{'STS-A-1호-MP-압축기-LEFT-XV-LIMIT-ON' }
```

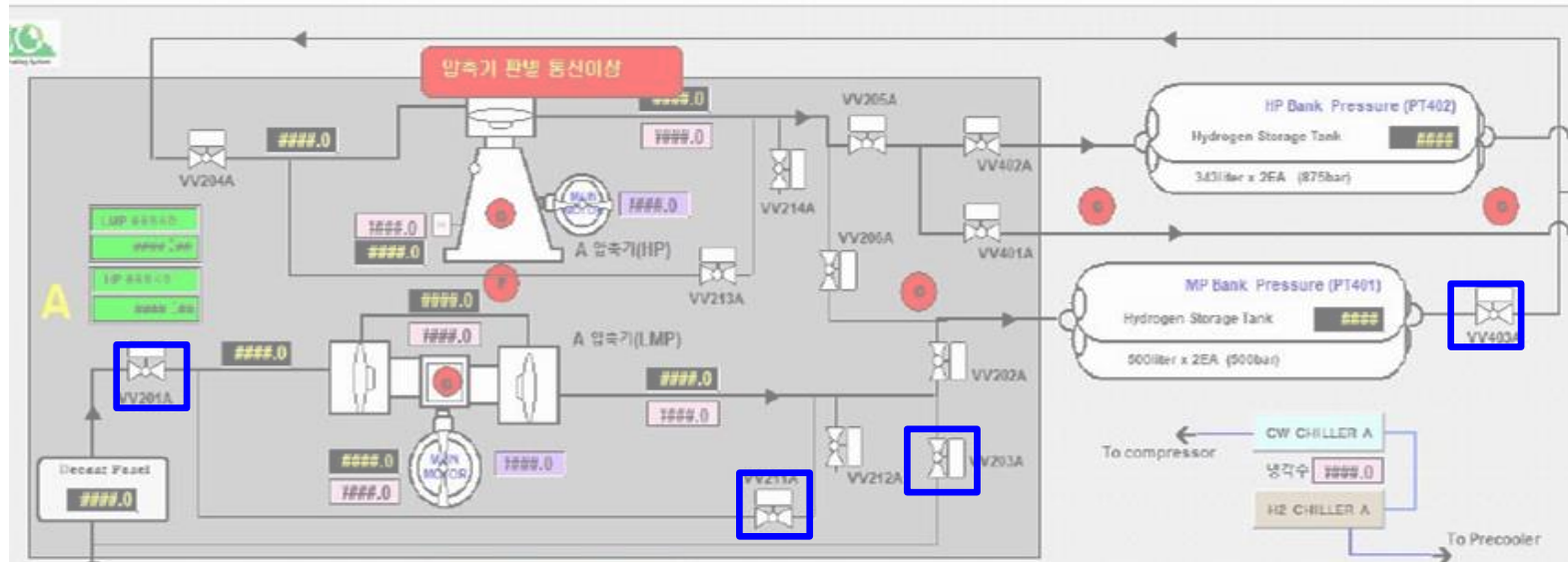
```
[row_filter,col_filtter,v_fillter]=find((target_sts_var(:,1)==1)& ...
(target_sts_var(:,2)==1)& (target_sts_var(:,5)==1)& ...
(target_sts_var(:,6)==0)&(target_sts_var(:,10)==0)& ...
(target_sts_var(:,11)==0));
```

```
[C2,ia2,ic2] = unique(sts_data3.Variables,'rows')
```

C = 7x4

	1	2	3	4
1	0	0	0	0
2	0	0	0	1
3	0	0	1	0
4	0	1	0	1
5	1	0	0	0
6	1	0	0	1
7	1	0	1	0

Refine modes – Domain insight



4x1 cell 배열

```
{'STS-A-1호-HP-압축기-RIGHT-XV-LIMIT-ON' }
{'STS-A-1호-LMP-압축기-BYPASS-XV-V_V-OPEN_CLOSE' }
{'STS-A-1호-LMP-압축기-인입-XV-V_V-OPEN_CLOSE' }
{'STS-A-1호-MP-압축기-LEFT-XV-LIMIT-ON' }
```

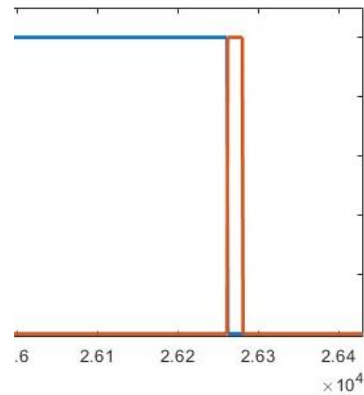
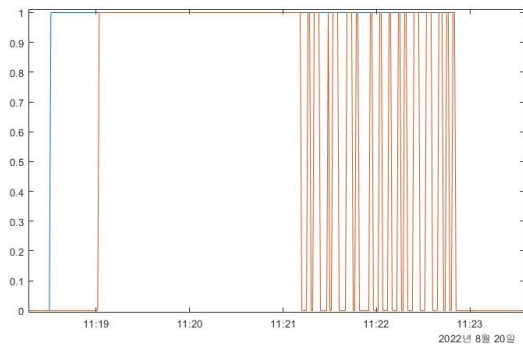
C = 7x4

	1	2	3	4
1	0	0	0	0
2	0	0	0	1
3	0	0	1	0
4	0	1	0	1
5	1	0	0	0
6	1	0	0	1
7	1	0	1	0

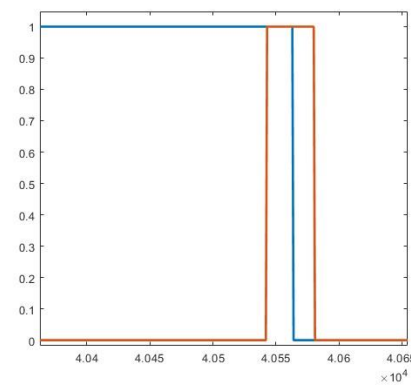


C2 = 4x4

0	0	0	1
0	0	1	0
1	0	0	1
1	0	1	0



Normal



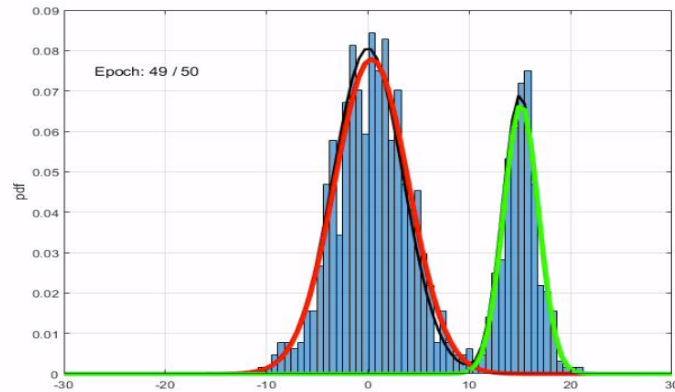
Abnormal

Estimate distributions of GM

Gaussian Mixture Model(GMM)

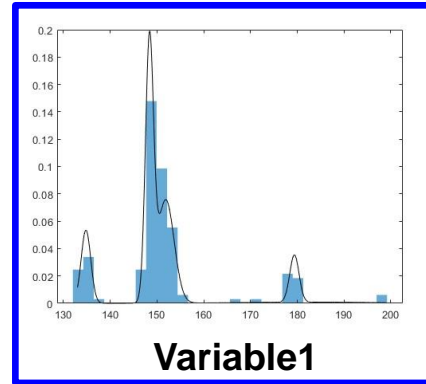
$$p(x) = \sum_{m=1}^M w_m p(x|N(\mu_m; \sigma_m)), \sum w_i = 1$$

$$\theta = (w_m, \mu_m, \sigma_m)$$

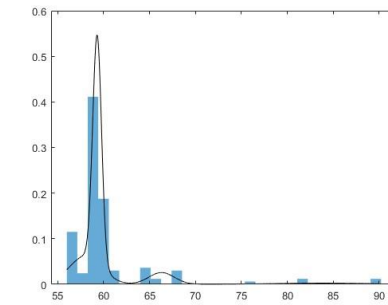
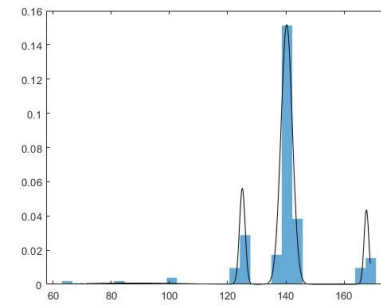
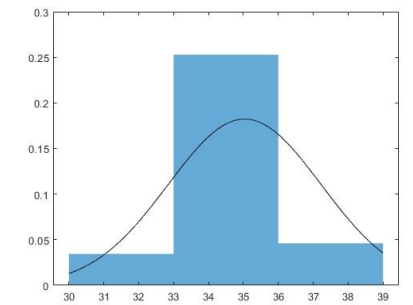
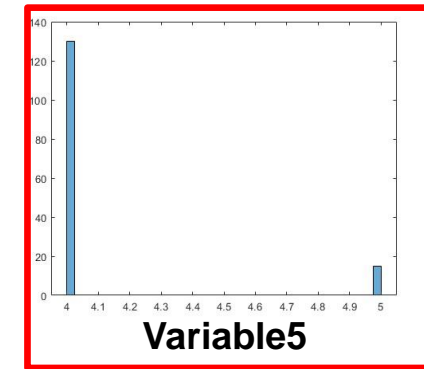
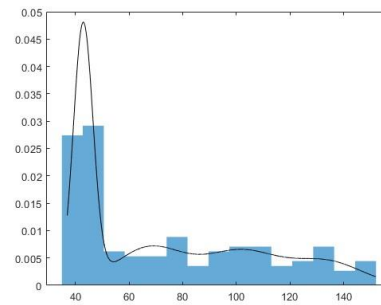
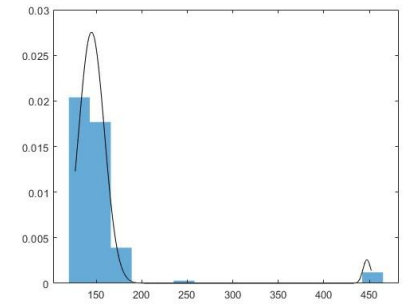
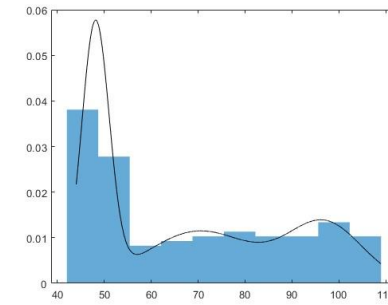


8x1 cell 배열

- { 'TAG-A-1호-LMP-압축기-1단-피츨-압력' }
- { 'TAG-A-1호-LMP-압축기-1단-피츨-온도' }
- { 'TAG-A-1호-LMP-압축기-2단-피츨-압력' }
- { 'TAG-A-1호-LMP-압축기-2단-피츨-온도' }
- { 'TAG-A-1호-LMP-압축기-회찰구-압력' }
- { 'TAG-A-1호-LMP-압축기-회찰구-온도' }
- { 'TAG-A-1호-LMP-압축기-인입-압력' }
- { 'TAG-A-1호-LMP-압축기-전류' }



mode1



Variable7

Variable8

Estimate Static/Dynamic probability

Estimate HMM-GMM Parameters $\lambda = (A, \pi_i, w_m, \mu_m, \sigma_m)$

- Estimate Initial condition of EM by K-means

```
numofele=[6,4,4,4];
variable=[1,2,1,1];
int_centers=cell(length(test_target3),1);
regularizationValue=0.1;
maxiter=1000;
options = statset('MaxIter',maxiter);

for i=1:length(test_target3)
    test_pdf_data=test_target3{i};
    test_pdf_data1=test_pdf_data(:,variable(i));
    int_centers{i}=kmeans(test_pdf_data1,numofele(i));
end
```

- Estimate Probability of Initial state

```
prior0=[0.5,0,0.5,0]';
prior1=zeros(length(test_target3),1);

for i=1:length(test_target3)
    prior1(i)=numel(find(ic2==i));
end
```

- Estimate GMM Parameters by EM algorithm

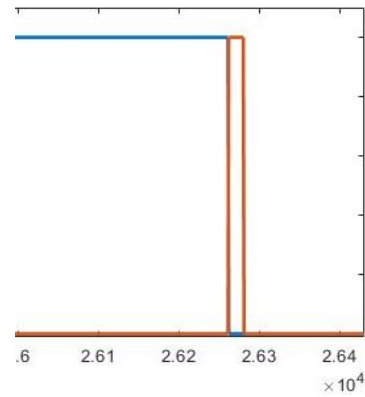
```
rng(4)
pdf_gmdist=cell(length(test_target3),1);
for i=1:length(test_target3)
    pdf_gmdist{i}=fitgmdist(test_target3{i}, numofele(i), ...
        'CovarianceType','full', ...
        'RegularizationValue',regularizationValue, ...
        'Options',options,'Start',int_centers{i})
end
```

- Estimate Probability of transition

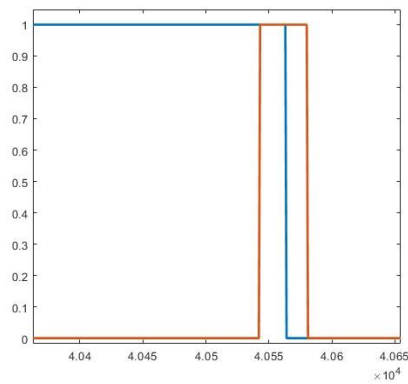
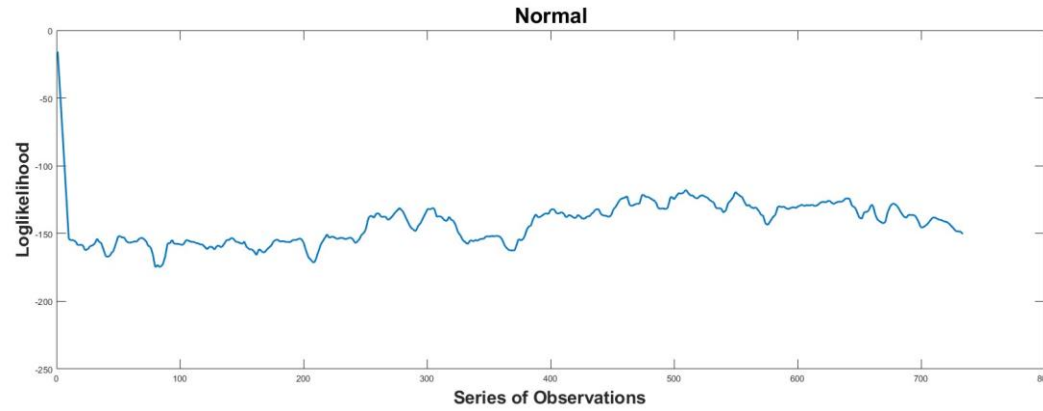
```
transmat=zeros(length(test_target3),length(test_target3));
for i=1:length(test_target3)
    for j=1:length(test_target3)
        transmat(i,j)=numel(find(and(ic2(1:end-1)==i,ic2(2:end)==j)==1));
    end
    transmat(i,:)=transmat(i,:)/sum(transmat(i,:));
end
```

Evaluate Log Likelihood

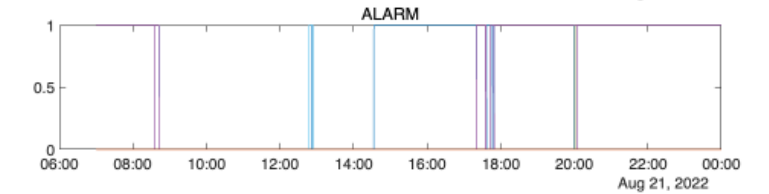
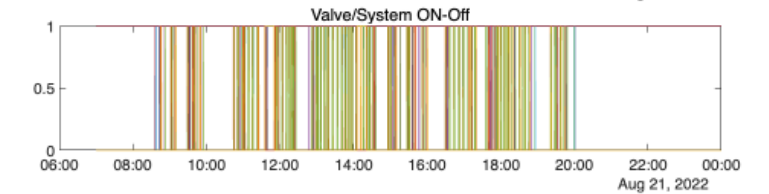
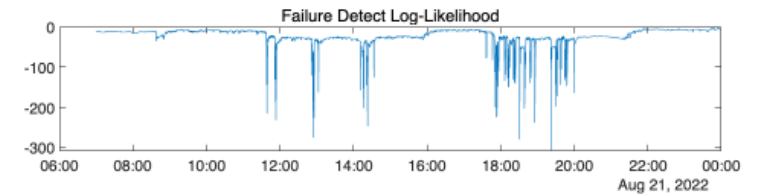
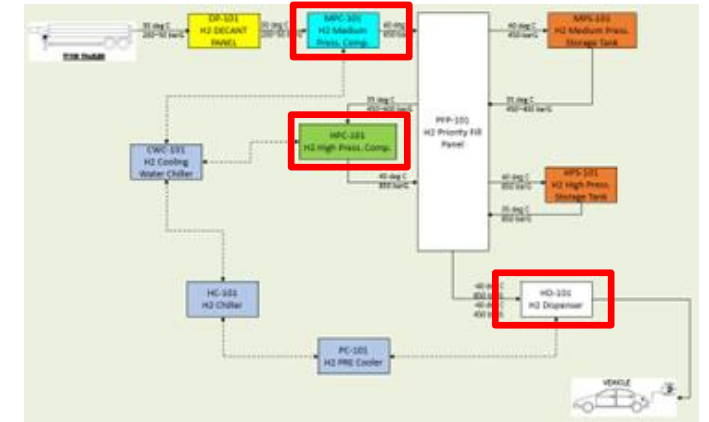
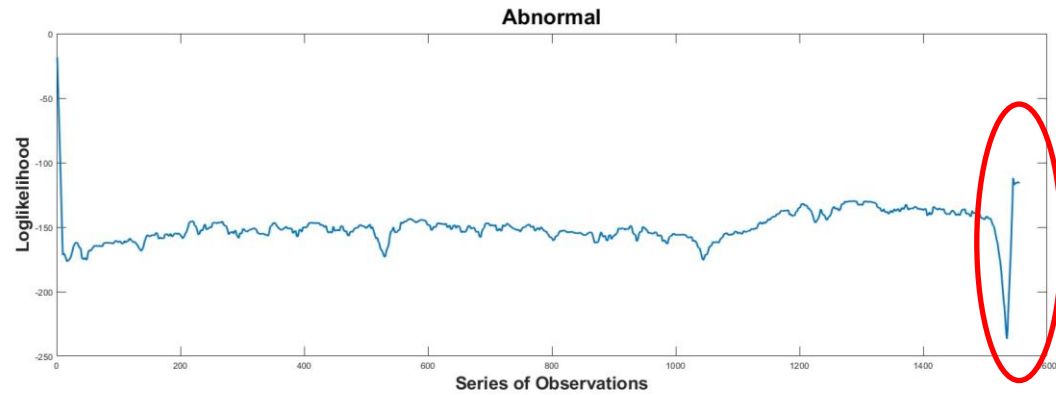
$$\text{Log}(P[o_t = v | o_{t-1}, \dots, o_{t-n}])$$



Normal



Abnormal



Web Application

수소모니터링 WebApp

주소: hmclnksvr:9989/webapps/home/session.html?app=app_0417

Zenius Dashboard...

Date: 2023년 5월 2일

중전소: 서산수소중전소

데이터 가져오기 완료! 경과시간: 15.61sec

Query

- 서산수소중전소
 - TAG
 - A-1호
 - CHILLER-BRAIN-인입-압력
 - CHILLER-냉각수-토출-온도
 - H2-CHILLER-냉매-온도
 - H2-인입-압력
 - H2-인입-질량-유량
 - HP-압축기-윤활유-압력
 - HP-압축기-인입-압력
 - HP-압축기-전류
 - HP-운전시간-분
 - HP-저장용기-COUNTER
 - HP-탱크-압력
 - LMP-압축기-1단-토출-압력
 - LMP-압축기-2단-토출-압력
 - LMP-압축기-윤활유-압력
 - LMP-압축기-인입-압력
 - LMP-압축기-전류
 - LMP-운전시간-분
 - MP-C-WATER-토출-온도
 - MP-탱크-압력
 - 증전기-공급-온도
 - 증전기-증전금액
 - 증전기-증전량
 - B-1호
 - CHILLER-냉각수-토출-온도
 - H2-CHILLER-냉매-온도
 - H2-인입-압력
 - HP-압축기-윤활유-압력

PLOT

Show Log

Failure Detect Log-Likelihood

Failure Detect! 이상지표 계산 중.....

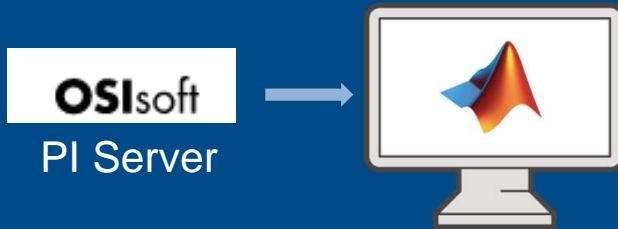
Time	Location	Attribute	Serial	TAG	Value
2023-05-02 08:32:16	서산수소중전소	ALM	A-1호	EMERGENCY-STOP	0
2023-05-02 08:32:16	서산수소중전소	ALM	A-1호	SYSTEM-전제-SHUTDOWN	0
2023-05-02 08:32:16	서산수소중전소	ALM	A-1호	냉각수-유량-LOW	0
2023-05-02 11:17:27	서산수소중전소	ALM	A-1호	H2-인입-압력-LOW	1
2023-05-02 11:19:40	서산수소중전소	ALM	A-1호	H2-인입-압력-LOW	0
2023-05-02 19:59:33	서산수소중전소	ALM	A-1호	EMERGENCY-STOP	1
2023-05-02 20:01:14	서산수소중전소	ALM	A-1호	냉각수-유량-LOW	1
2023-05-02 20:08:32	서산수소중전소	ALM	A-1호	SYSTEM-전제-SHUTDOWN	1

오류 5:14
2023-05-07

Recap: MTALAB offerings augment the AI workflow

Data Preparation

Industrial Communication Tool



Importing historical PI data into MATLAB Desktop for data exploration or algorithm development

AI Modeling

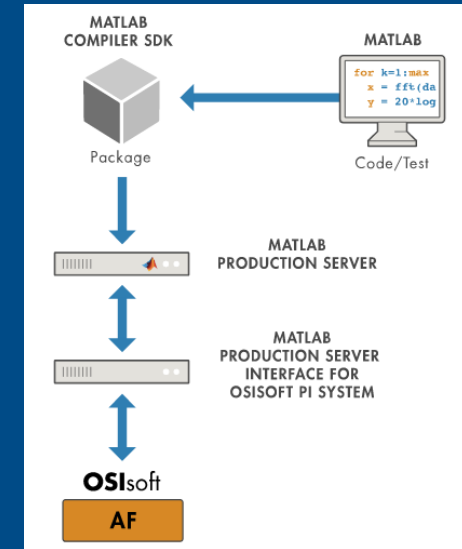
MATLAB Parallel Server



Accelerate training using Parallel Server

Deployment

MATLAB Production Server



Deploy analytic models and provide microservice APIs

MATLAB EXPO

Thank you



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