Acoustic-Emission Structural Health Monitoring & Prognostics Health Management

FeaturePump

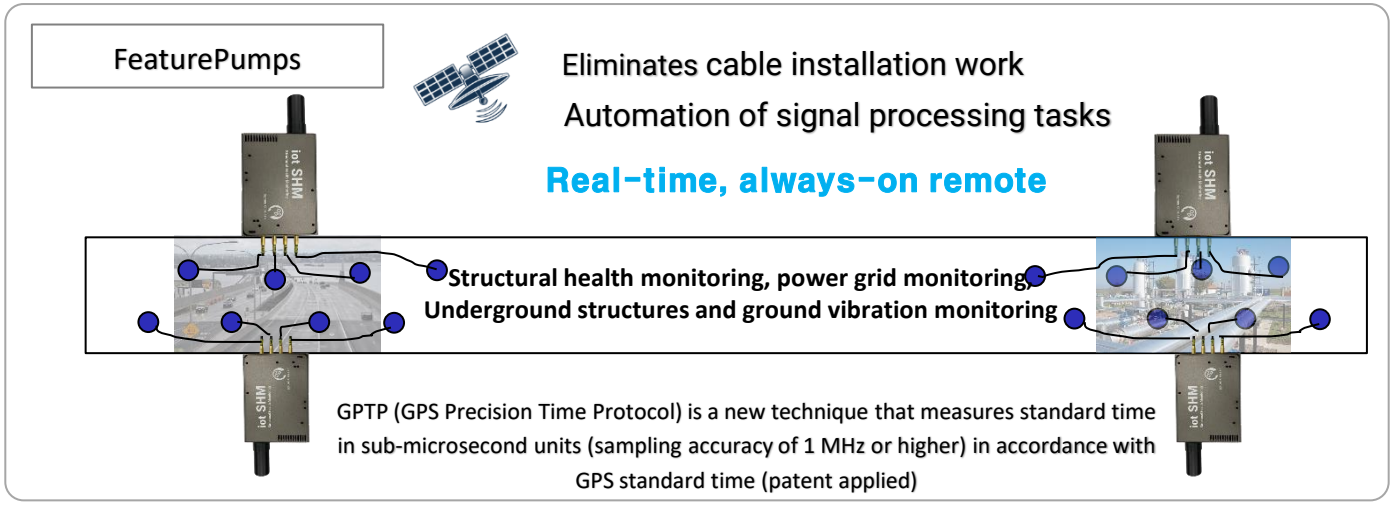
Streaming features of intelligent digital-twin diagnostic system

Product Description

www.secure-ai.biz

IoT FeaturePump

❑ **IoT FeaturePump provides automated signal processing tasks, synchronized with ultra-precise timing GPS clocks without the need for long-distance cables in the wide area of signal monitoring sites**



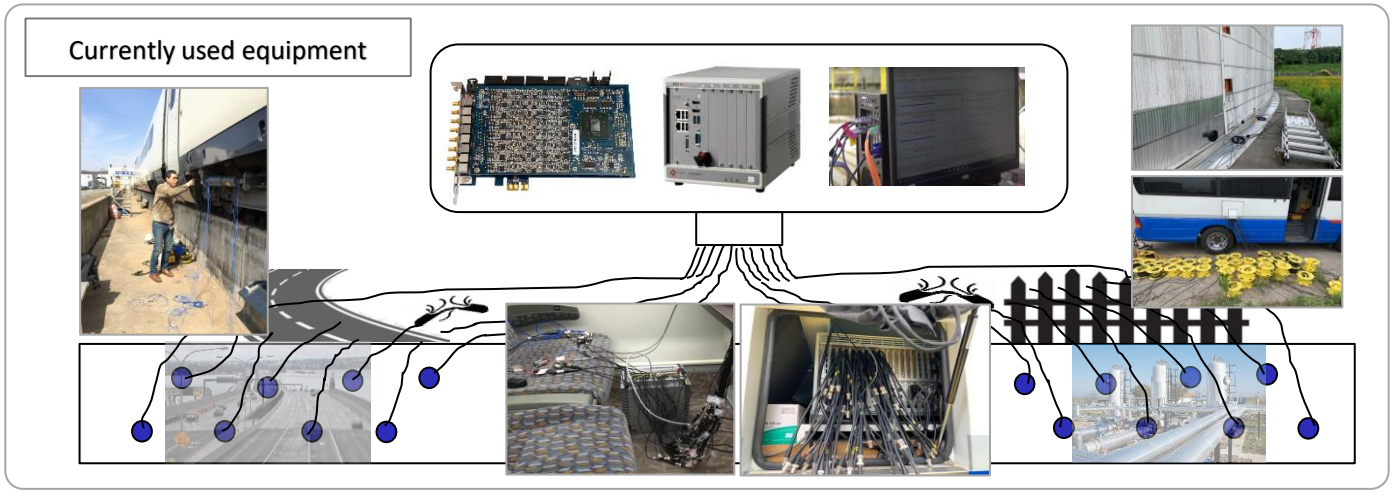
When acquiring 40 sensor channel signals with a measurement area radius of 500m

[Use case of FeaturePump]

: Prepare ten 4-channel FeaturePumps

: No need to purchase acquisition software: Regular diagnosis is possible using the signal processing results from the measuring instrument itself.

: Abnormalities can be tracked and managed on the management server



[Use case of conventional DAQ system]

: Prepare five 8-channel DAQ boards to the site.

: Prepare 40 sensor cables of 500 m

: Cables must be connected from the test site to the equipment (for fences and road obstacles).

: Obtain acquisition software to acquire and store data on site

: Engineers must perform signal processing using signal processing software

: One-shot diagnosis on the time of measurement, not to prevent accidents at any point in time

Applications of IoT FeaturePump

- ❑ Prevention of accidents in underground pipes (gas oil, water supply, heat transmission pipes)
- ❑ Prevention of accidents in D.E grade facilities, buildings older than 30 years, and facilities used by the public.
- ❑ Prevention of collapse accidents on railways, roads and bridges
  - Accident prevention system for major arterial road bridges
  - Road tunnel collapse and attachment fall prevention system
- ❑ Prevents collapse of steep ground cut surfaces, ground sinkholes, and landslide accidents during the rainy season.
- ❑ Prevention of accidents at construction sites
  - Slab collapse during concrete pouring at construction site,
  - Worker fall accidents and support form collapse,
  - Collapse of elevated crane support
- ❑ Safety evaluation of undersea tunnels, offshore structures and undersea pipelines
- ❑ Safety evaluation of structures related to the aviation and space industry
- ❑ Risk assessment of hydrogen and LNG gas, oil storage tanks and pipes

Building collapse accident

Tilt/fiber optic sensors detect the accidents almost at the time of occurrence

➡ **Serious disasters are prevented by clustering the patterns of diagnostics feature data streamed from field-installed FeaturePumps**

FeaturePump Specification

❑ **FeaturePump has two basic configurations to reflect the requirements of sensor installation and signal monitoring:**

- **Four channel inputs of AE and vibration sensors are sampled with high speed and the data of each channel are processed concurrently**
- **Tow channel inputs of parametric or operational sensors are sampled providing the current operational status**
- **Stream features of each channel are transmitted to the user server through various connections through RJ45 ethernet cable and WiFi of Raspberry CM (configuration 1), NB-IoT and HaLow WiFi module for connectivity over long distance, which are connected by the serial interface of FeaturePump UART and SPI (configuration 2)**

❑ **External specifications and power inputs**

Item	Description
Size	~146 x 96 x 33 mm
SSD memory	32 GB
DC input voltage	5 volt or 12 volt
Operational temperature	from -35° C to 60° C
Power consumption	4 Watt
LEDs of power and operation status	(included)
Digital input and output pins	4 ports
Interface mode of Raspberry CM	1 SPI, 1 UART and 4 GPIO
Battery (backup)	(optional)
DC power supply	5 ~ 24 VDC
AC power supply	220 VAC adapter (5VDC @1A)
PoE (optional)	Raspberry CM4 with PoE adaptor

FeaturePump Specification

❑ **Signal acquisition specifications of AE and vibration channel inputs**

Item	Description
Number of channels	4
Frequency bandwidth	5 kHz ~ 1 MHz
Analog filter	2 Bandpass filters per channel
Digital filter	256 FIR filters
Sampling rate	20 MSPS
A/D converter resolution	16 bits
Sample number of hit waveform	1,000 ~ 10,000 samples per hit
IOT device synchronization accuracy (between channels and IoT devices)	Up to 1/100,000,000 second (10ns) (Channels are simultaneously sampled with the period of 50ns, so there is no time difference between the samples)
AE sensor connector type	SMB Jack Female

❑ **Signal acquisition specifications of general operational channel inputs**

Item	Description
Number of channels	2
Frequency bandwidth	0 - 1KHz
Sampling rate	100 KSamples/second
A/D converter resolution	12 bits or 16 bits
Input signal range	0 - 4 V
Voltage amplification ratio	x1
Connector type	Terminal block

Real Time Features of FeaturePump Streaming

- ❑ Hit Count (Ne) : Number of hits accumulated during a given time span of acquisition
- ❑ Hit arrival time : Event arrival time
- ❑ Duration (t_D) : Time over which the waveform exceeds the trigger threshold when a hit occurs.
- ❑ Peak Amplitude (A) : Maximum amplitude of waveform in duration time
- ❑ RMS (V_rms) : Sum of absolute values in duration time, divided by duration time
- ❑ Rising time (t_R) : Time from the instant of exceeding the threshold to the instant of reaching at amplitude peak
- ❑ Slope (s) : Maximum amplitude divided by Rising time

$$E_{ENV} = \sum_{k=0}^{n} |H(s(t))| \Delta t \times 100 \times 1E6$$

- ❑ Ring down Count (N) : Number of crossing the threshold
- ❑ MARSE (Measured Area of Rectified Signal Envelope) [uV.s]

$$S_{tr} = \sum_{k=0}^{n} |s(t)| \Delta t \times 100 \times 1E12$$

- ❑ Strength [pV.s]
- ❑ Energy : Sum of sample squares in duration time

$$E_{abs} = \sum_{k=0}^{n} |s(t)|^2 \Delta t / R \times 1E18$$

- ❑ Spectrum amplitude
- ❑ RMS of power spectrum

$$G(k) = \frac{Magitude[FFT(S(n))]}{N} = \frac{\sqrt{real[FFT(S(n))]^2 + imag[FFT(S(n))]^2}}{N}$$

- ❑ Spectrum peak (G0, G1) : First and second maximum values of spectrum amplitude
- ❑ Frequency (F0, F1) : Frequency locations of the first and second maximum values of the spectrum amplitude
- ❑ Maximum amplitude of signal waveform

$$S_{rms} = \sqrt{\frac{\sum_{k=0}^{n} [real[FFT(S)]^2 + imag[FFT(S)]^2]_k}{N}}$$

센서네트워크 기반 국내외 최초 초정밀 상태진단 기술

❑ IoT SHM **Feature Pump**는 **국제표준시간으로 특징 데이터와 초정밀 시간소인(Time Stamp)을 실시간 제공함** (특허출원)

현장시설에 설치된 IOT SHM 계측기들

IoT SHM EDGE DEVICE
상태진단 데이터

AE센서 신호획득 4 채널
환경센서 2 채널 (응력, 압력 등)

IOT 통신모뎀
듀얼코어 MCU/RTOS
반도체 프로세서 로직

LTE, WiFi, Ethernet
LwM2M, OneM2M 적용

사용자 서버

데이터처리 프로그램
스트리밍 AE 특징변수 통계처리 및 DB화

패턴분석 프로그램
AE 특징변수 인공지능 패턴분석

[UART연결 컴퓨터]

❑ IoT SHM **Feature Pump**는 국내외 최초로 **설치거리 제한없이 손상영역을 분별**하여 진단하는 음향방출/진동신호 분석장비

우측 진단 영역

128.6 m

10m

좌측 진단 영역

148.89m

맨홀-B-02

(1) TD_stamp < TA_stamp

손상영역 분별

A채널에서 AE신호 도착시점 (TA_stamp)

D채널에서 AE신호 도착시점 (TD_stamp)

맨홀-B-01

(2) 160 μ sec 차이 [센서간격 80cm]
(1 μ sec : 백만분의 1초)

▶ 맨홀2 장비는 TD_stamp > TA_stamp 조건을 만족하는 A채널 특징데이터를 사용하여 좌측 배관을 진단하여함

국내외 최초 건전성 데이터 실시간 제공 **Feature Pump**

❑ 센서네트워크 지역내 IoT SHM **Feature Pump**는 자신의 위치를 자동 탐지하여 센서 위치 정보를 실시간 제공하며 (특허출원)

❑ 초정밀 이벤트 Time Stamping으로 각 채널별로 손상발생의 시점 정보와 34개 특징변수 데이터를 실시간 제공함 (특허출원)

IoT Operation	
Version:	AE SHM
Device ID:	1245
Connection Type:	Serial
A-CH On/Off:	ON
B-CH On/Off:	ON
C-CH On/Off:	ON
D-CH On/Off:	ON
THRESHOLD:	6000
Hit Definition Time[us]:	500
Hit Lock Time[us]:	500
Local_Y0[m]:	5340.6
Local_X0[m]:	5689.3
A-Senosr X[m]:	5341.62
B-Senosr X[m]:	5341.85
C-Senosr X[m]:	5342.16
D-Senosr X[m]:	5343.05
A-Senosr Y[m]:	5690.59
B-Senosr Y[m]:	5689.64
C-Senosr Y[m]:	5691.07
D-Senosr Y[m]:	5692.74

▶ Local Yo : 계측기 위도의 분각도 범위 [0.000 : 9.999] x 1800m

▶ Local Xo : 계측기 경도의 분각도 범위 [0.000 : 9.999] x 1855m

▶ Sensor Xs, Ys = Xo, Yo + Xi, Yi

Xi, Yi : 각 센서와 계측기의 거리 (센서 설치시 IoT SHM 기기에 입력)

▶ 구조물진동 모달해석 (원격자동화)

Transinet Features	
FeatureType:	Transient
AcqPeriod:	500ms
Channel:	CHA
UTC_Seconds:	5210
Stamp_InitialAmp[us]:	212883.0
Initial Amplitude:	21028
Initial Duration[us]:	499.3
Initial RisingTime[us]:	335.5
Initial RingCount:	3051
Initial InitCount:	197
Initial AbsEnergy:	7121098
Initial Energy:	4609074
Initial Strength:	55796775
Initial RMS:	439
Stamp_MaxAmp[us]:	213509.0
Maximum Amplitude:	22128
Duration_Of_Max[us]:	482.0
RisingTime_Of_Max[us]:	294.0
RingCount_Of_Max:	3219
InitCount_Of_Max:	111
AbsEnergy_Of_Max:	3680940
Energy_Of_Max:	18603720
Strength_Of_Max:	60004180
RMS_Of_Max:	1087
Median Amplitude:	15360
Median RMS:	916
Mean ParametricValue:	274
Hit Rate:	8

채널별 돌발형 특징변수 개수 : 23 개
(운영상태 변수 : 1개)

Transinet Features	
FeatureType:	Transient
AcqPeriod:	500ms
Channel:	CHD
UTC_Seconds:	5210
Stamp_InitialAmp[us]:	212811.0
Initial Amplitude:	19974
Initial Duration[us]:	288.6
Initial RisingTime[us]:	48.7
Initial RingCount:	2543
Initial InitCount:	198
Initial AbsEnergy:	3031007
Initial Energy:	4166801
Initial Strength:	33676734
Initial RMS:	1346
Stamp_MaxAmp[us]:	212811.0
Maximum Amplitude:	19974
Duration_Of_Max[us]:	288.6
RisingTime_Of_Max[us]:	48.7
RingCount_Of_Max:	2543
InitCount_Of_Max:	198
AbsEnergy_Of_Max:	3031007
Energy_Of_Max:	4166801
Strength_Of_Max:	33676734
RMS_Of_Max:	1346
Median Amplitude:	14848
Median RMS:	781
Mean ParametricValue:	262
Hit Rate:	5

채널별 연속형 특징변수 개수 : 11 개
(스펙트럼 변수 : 6 개)

Continuous Features	
FeatureType:	Continuous
AcqPeriod:	1000ms
Channel:	CHD
SpectralPeak_1st:	129216
Freq_SpecPeak_1st:	47
SpectralPeak_2nd:	158272
Freq_SpecPeak_2nd:	100
SpectralCrestValue:	78900
Freq_SpecCrestValue:	100
MaxAmplitude_Average:	37087
RMS_Average:	2021
MagnitudeSum_Average:	2812
Energy_Average:	29512
Strength_Average:	15637

▶ 누수 스펙트럼 에너지 : $E_D(f)$

▶ Device 1245, 1246의 A, D 이벤트 UTC 발생시간: 5210 〈01시26분50초〉 (한국_HOUR = UTC_HOUR + 9)

▶ 무선 원격 Device 1245-A와 1246-D의 IoT SHM 기기 간 이벤트 발생시간 차이 [μ sec]: Δ Time_AD

TA_stampF - TD_stampF = 72 μsec

TA_stampM -TD_stampM = 698 μsec

▶ 이벤트 발생시점으로 손상위치 (Xe) 계산 (1차원 직선 경우, C : AE 전파속도)

Xe –Xs_A = Δ Time_AD * C [5,000,000 mm/s], measured by PLB Test + 0.5 * (Xs_D - Xs_A)

IoT 상태진단 자동화 기기

❑ IoT SHM **Feature Pump**는 특징데이터 스트리밍 방식으로 신호 분석을 위한 소프트웨어가 필요치 않음

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	idx	Date_Time	FeatureType	Channel	Threshold	iggered Val	Hit Rate	lian Dura	an Rising	ian RingC	ain Amplit	edian Enve	dian Envel	in Magnitud	ax Duratio	ix RisingTi	x RingCo	ax Amplitu	np_MaxAmp	me_MaxAm	Max Energy	ax Envelop	Magnitude	Parametric	Hit GapTime
2	0	20231110:194121	Transient	CHA	6000	6327	43	4	2	1	1494	151	1177	276	5	3	1	11573	833106	1:36:57	689173	216658	642240	193	11
3	1	20231110:194121	Transient	CHA	6000	6122	39	4	2	1	644	704	1202	795	5	3	1	11741	1632059	1:36:58	707769	217762	644096	192	13
4	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
5	300	20231110:194417	Transient	CHA	6000	6155	42	4	2	1	1338	1385	323	455	5	3	1	11658	1381678	1:37:42	681557	225736	637568	192	11
6	301	20231110:194418	Transient	CHA	6000	6155	45	4	2	1	700	518	1238	369	5	3	1	11458	1962221	1:37:42	688583	208286	633088	191	11
7		4m56s																							

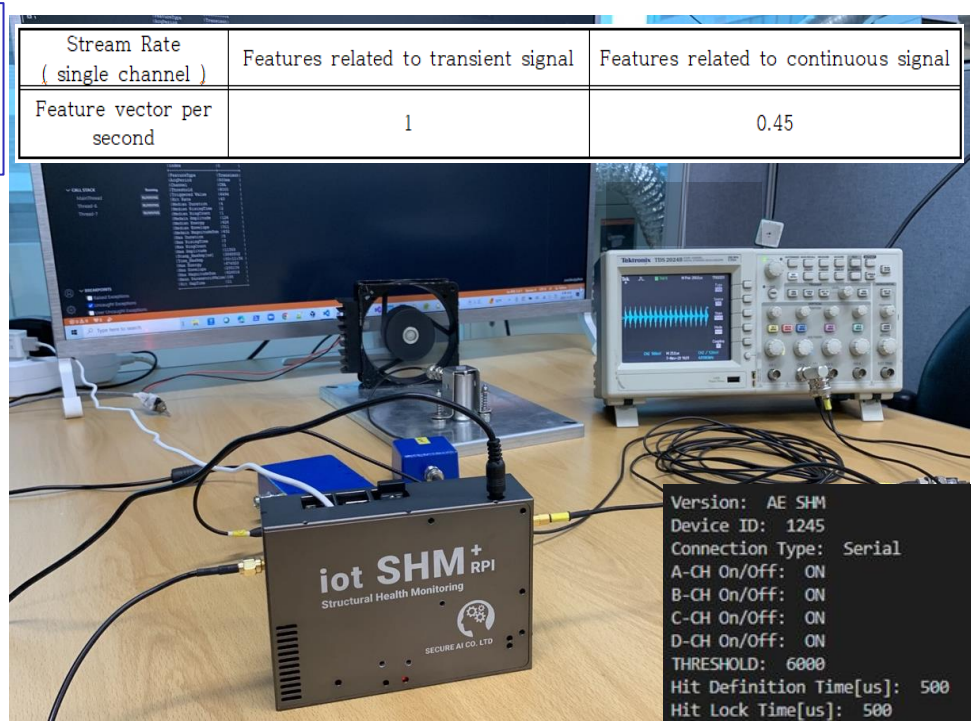
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	idx	Date_Time	FeatureType	Channel	ectralPeak_1st	_SpecPeak_1st	ctralPeak_2nd	SpecPeak_2nd	tralCrestValue	pecCrestValue	litude_Average	RMS_Average	eSum_Average	nergy_Average	ength_Average
2	0	20231110:193536	Continuous	CHA	87456	70	129936	105	59107	105	11578	710	693	1251	1560
3	1	20231110:193537	Continuous	CHA	86160	40	121648	105	56684	105	11690	699	681	1240	1533
4	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
5	300	20231110:194208	Continuous	CHA	77376	40	129840	105	62806	105	11596	709	688	1240	1561
6	301	20231110:194208	Continuous	CHA	84208	40	130816	105	61573	105	11712	702	684	1230	1530
7		11m12s													

index	0
FeatureType	Transient
AcqPeriod	500ms
Channel	CHA
Threshold	6000
Triggered Value	6466
Hit Rate	45
Median Duration	4
Median RisingTime	2
Median RingCount	1
Medain Amplitude	266
Median Energy	159
Median Envelope	294
Medain MagnitudeSum	770
Max Duration	5
Max RisingTime	3
Max RingCount	1
Max Amplitude	11513
Stamp_MaxAmp[us]	936665
Time_MaxAmp	00:21:14
Max Energy	757162
Max Envelope	249418
Max MagnitudeSum	630592
Mean ParametricValue	203
Hit GapTime	11

The existing SHM system reads hundreds of waveform data files from a folder and processes signals after saving the measurement data, which takes at least 3 hours and is not a stream method.

index	0
FeatureType	Continuous
AcqPeriod	1000ms
Channel	CHA
SpectralPeak_1st	183072
Freq_SpecPeak_1st	20
SpectralPeak_2nd	99104
Freq_SpecPeak_2nd	105
SpectralCrestValue	90013
Freq_SpecCrestValue	20
MaxAmplitude_Average	11622
RMS_Average	828
MagnitudeSum_Average	778
Energy_Average	1413
Strength_Average	1815

Stream Rate (single channel)	Features related to transient signal	Features related to continuous signal
Feature vector per second	1	0.45



특징변수 스트림을 이용한 인공지능 패턴분석

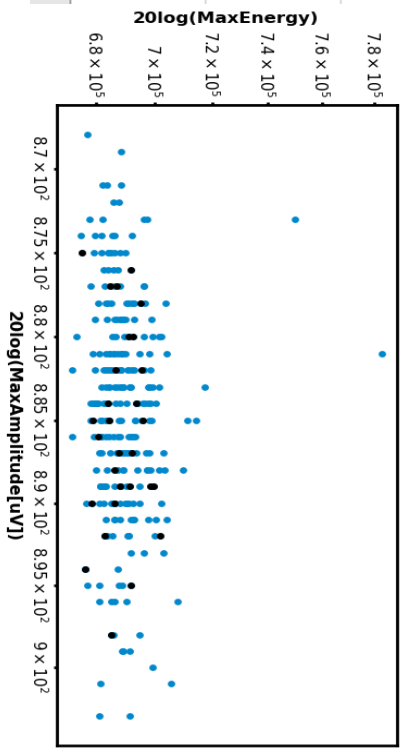
❑ **사용자 분야별 특화된 분류 및 인공지능(ML) 기법을 적용하여 생산제품, 생산장비 및 시설물 결함을 실시간 추적관리**

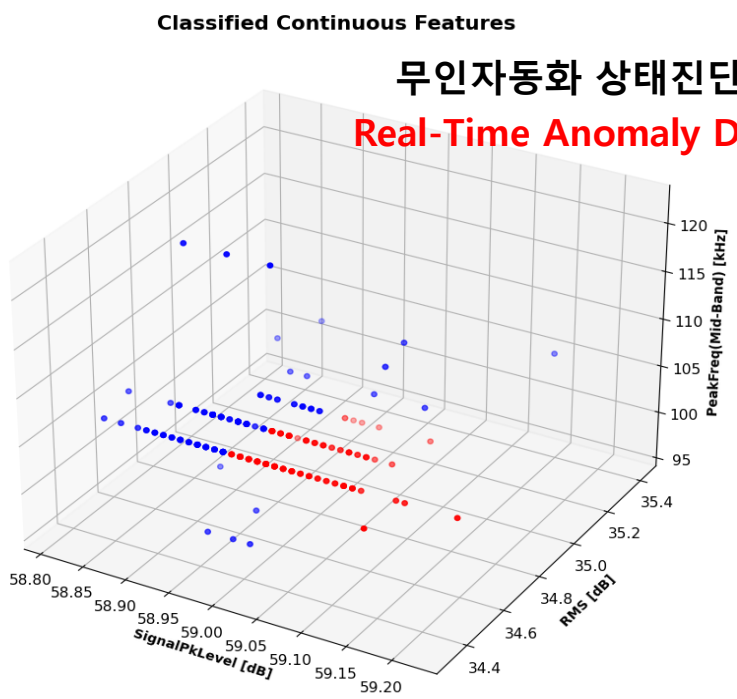
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	idx	Time	LowPeak	OfLowPeak	MidPeak	OfMidPeak	ectralCrest	reqOfCrest	SignalLevel	RMS	Magnitude	Energy	Strength
2	0	70536	87456	70	129936	105	59107	105	883	54	53	1251	1560
3	1	70537	86160	40	121648	105	56684	105	892	53	52	1240	1533
4	---	---	---	---	---	---	---	---	---	---	---	---	---
5	270	70927	81024	40	125696	105	57364	105	895	54	53	1231	1528
6	271	70928	77376	40	129840	105	62806	105	885	54	52	1240	1561

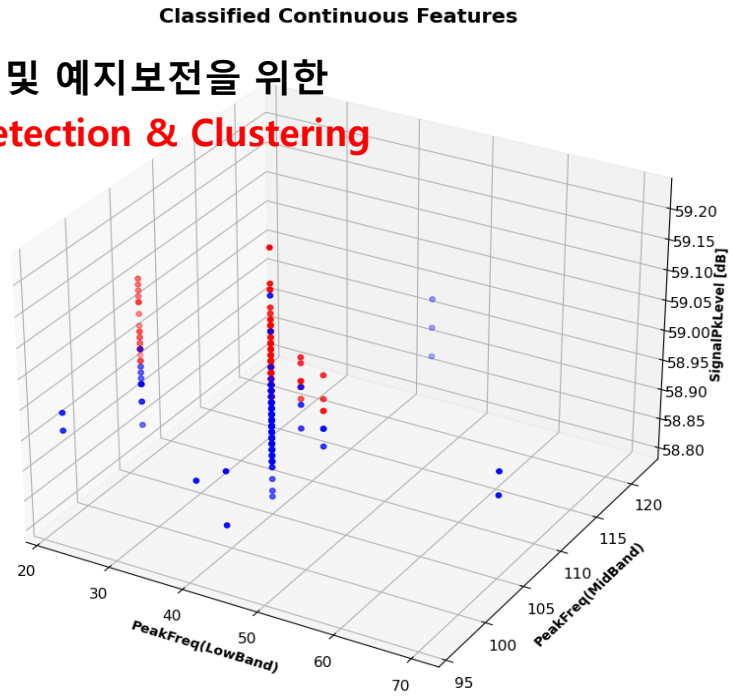
전처리 AE_features 프로그램
[기본적인 전처리 관련 Python코드 실행]

	A	B	C	D	E	F	G	H	I
1	idx	imeOfArrival	Amplitude	RiseTime	Duration	Energy	ABS_ENERGY	Counts	HitRate
2	0	5817.166621	882.95	1.2	2	689173	216658	1	43
3	1	5818.326412	895.77	1.2	2	707769	217762	1	39
4	---	---	---	---	---	---	---	---	---
5	287	5861.197703	882.49	1.2	2	683116	213685	1	47
6	288	5862.276336	889.43	1.2	2	681557	225736	1	42

Pattern AE_features 프로그램
[기본적인 패턴분류 관련 Python코드 실행]







무인자동화 상태진단 및 예지보전을 위한
Real-Time Anomaly Detection & Clustering

IoT SHM **Feature Pump**의 특징

- 실시간 분석 및 의사결정이 가능하여 대기 시간을 최소화하고 이벤트 트리거에 신속하게 대응할 수 있음
- 특징 추출 및 인공지능 패턴 분석으로 정제된 데이터만 전송함으로 전송 속도를 초당 500KB 미만으로 함
- 중앙서버나 클라우드에 대한 연결이 중단된 경우에도 자율적으로 작동됨
- IoT SHM 계측기는 조치나 경고를 즉시 발생시킬 수 있으므로 사고방지 경고시스템의 효율성이 향상됨
- 센서 네트워크의 분산 아키텍처를 목표로 대규모 배포에 필요한 확장성과 유연성을 지원함