KORE A 2020

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JMP 머신러닝 기법을 적용한 롤러베어링 실시간고장감지 모니터링시스템 구축

- 2020. 11.

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진행 프로세스

JMP 기반 통계적 성능지표 선정

롤러베이링 가속도 데이터

→

통계적 성능지표 선정
Peak, r.m.s,
Kurtosis,
Crest factor,
Clearance factor,
Impulse factor,
Shape factor r.m.s,
Entropy, Skewness, s.m.r,
5th n.m, 6th n.m,
Mean, Shape factor s.m.s

→

Python/JMP 실시간 이상감지 모니터링 시스템

JMP script
기반
머신러닝 모델링

Neural Network,
Boosted Tree,
K Nearest Neighbors,
Support Vector
Machines

→

머신러닝 기반
모니터링 시스템
구축

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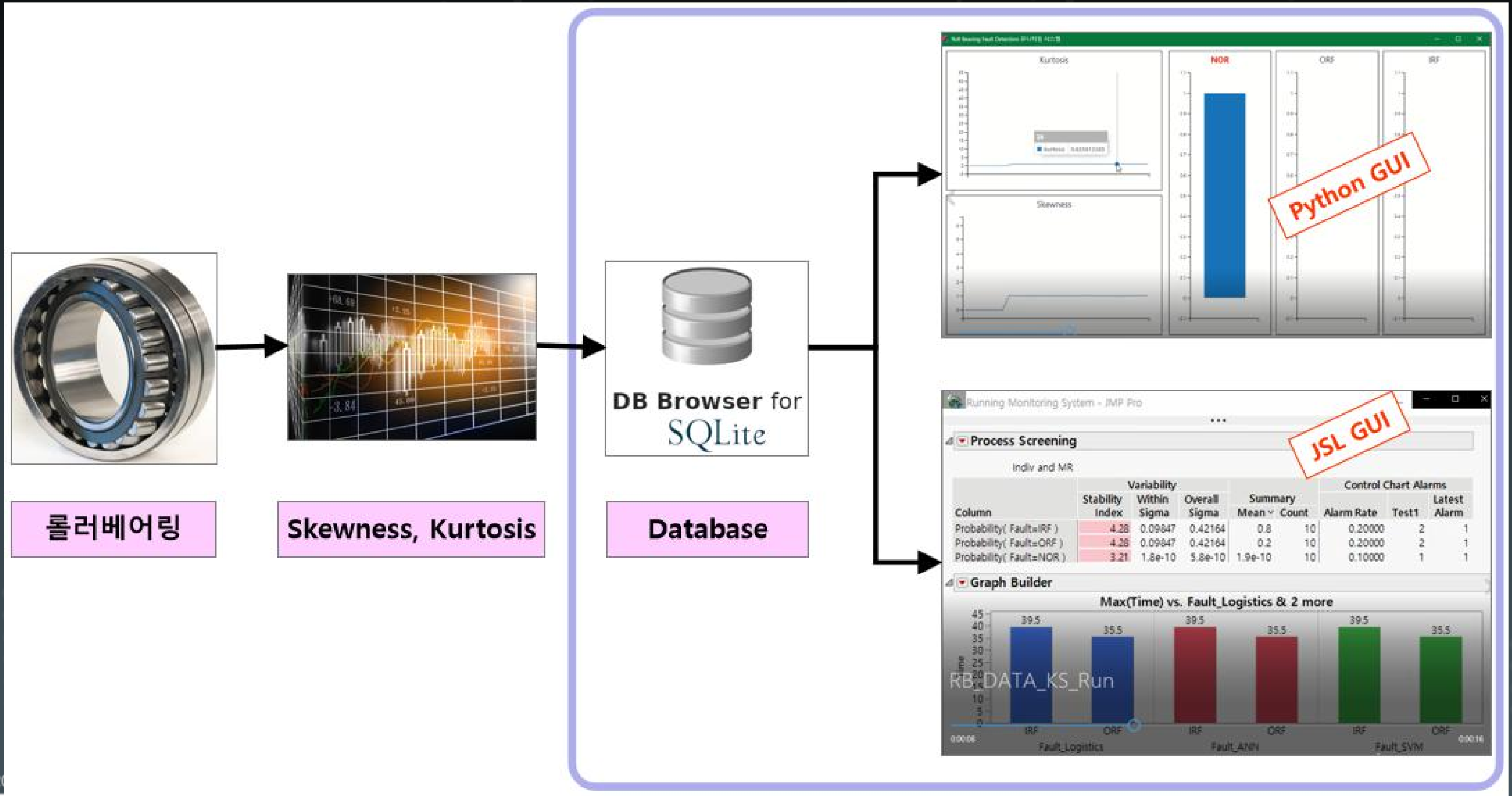
과제 구현 이상 감지 모니터링 시스템



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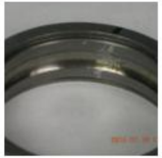
고장 데이터

- 3 baseline conditions & 3 outer race fault conditions
  > 270 lbs of load, sample rate of 97,656 cps, for 6 seconds
- 6 outer race fault conditions & 6 inner race fault conditions
  > 25/50, 100, 150, 200, 250, 300 lbs of load, sample rate of 48,828 cps, for 3 seconds

Bearing Fault Dataset

A bearing fault dataset has been provided to facilitate research into bearing analysis. The dataset comprises data from a bearing test rig (nominal bearing dat
outer race fault at various loads, and inner race fault and various loads), and three real-world faults.



Inner Race

데이터(정상, 고장, 고장)

NOR(Normal), ORF(Outer Race Fault), IRF(Inner Race Fault)

The test rig was equipped with a NICE bearing with the following p

- Roller diameter: rd = 0.235
- Pitch diameter: pd = 1.245
- Number of elements: ne = 8
- Contact angle: ca = 0

The data set1,2 comprises the following, and can be downloaded as a zip file package he:**Fault Data Sets**

- 3 baseline conditions: 270 lbs of load, input shaft rate of 25 Hz, sample rate of 97,656 sps, for 6 seconds
- 3 outer race fault conditions: 270 lbs of load, input shaft rate of 25 Hz, sample rate of 97,656 sps for 6 seconds
- 7 outer race fault conditions: 25, 50, 100, 150, 200, 250 and 300 lbs of load, input shaft rate 25 Hz, sample rate of 48,828 sps for 3 seconds (bearing resonance was found be less than 20 kHz)
- 7 inner race fault conditions: 0, 50, 100, 150, 200, 250 and 300 lbs of load, input shaft rate of 25 Hz, sample rate of 48,828 sps for 3 seconds

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롤러베어링 고장 감지를 위한 통계적 성능지표 선정

- Peak, r.m.s, Kurtosis, Crest factor, Clearance factor, Impulse factor
- Shape factor r.m.s, Entropy, Skewness, s.m.r, 5th n.m, 6th n.m
- Mean, Shape factor s.m.s

Parameters	Equations	Parameters	Equations	Parameters	Equations
Peak(s_{peak})	$max(\lvert s \rvert)$	Shape factor	$\frac{s_{rms}}{\frac{1}{N}\sum_{n=1}^{N}\lvert s_n \rvert}$	Mean($\bar{s}$)	$\frac{1}{N}\sum_{n=1}^{N} s_n$
Root-mean-square (s_{rms})	$\sqrt{\frac{1}{N}\sum_{n}^{N} s_n^2}$	Entropy	$-\sum_{n=1}^{N} p_n \cdot \log_2 p_n$	Shape factor square-mean-root	$\frac{s_{smr}}{\frac{1}{N}\sum_{n=1}^{N}\lvert s_n \rvert}$
Kurtosis	$\frac{1}{N}\sum_{n=1}^{N}\left(\frac{s_n - \bar{s}}{\sigma}\right)^4$	Skewness	$\frac{1}{N}\sum_{n=1}^{N}\left(\frac{s_n - \bar{s}}{\sigma}\right)^3$		
Crest factor	$\frac{max(\lvert s \rvert)}{s_{rms}}$	Square-mean-root (s_{smr})	$\left(\frac{1}{N}\sum_{n=1}^{N}\sqrt{\lvert s_n \rvert}\right)^2$		
Clearance factor	$\frac{s_{peak}}{s_{smr}}$	5th normalized moment	$\frac{1}{N}\sum_{n=1}^{N}\left(\frac{s_n - \bar{s}}{\sigma}\right)^5$		
Impulse factor	$\frac{max(\lvert s \rvert)}{\frac{1}{N}\sum_{n=1}^{N}\lvert s_n \rvert}$	6th normalized moment	$\frac{1}{N}\sum_{n=1}^{N}\left(\frac{s_n - \bar{s}}{\sigma}\right)^6$		

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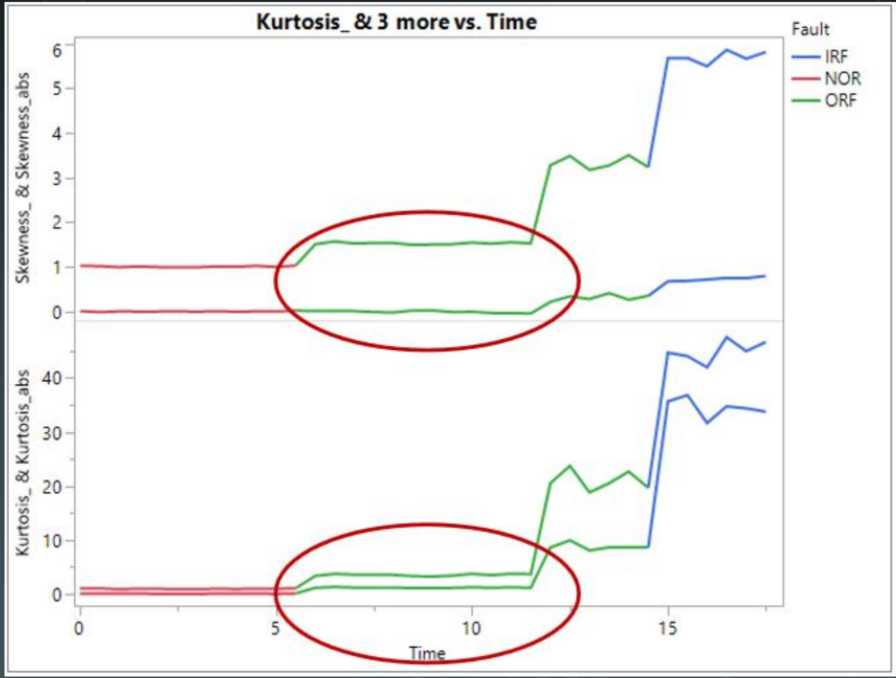
롤러베어링 고장 감지를 위한 통계적 성능지표 선정

- 롤러베어링 가속도 신호에 절대값을 취하고 0.5초 단위로 에버리징

  > NOR(Normal), ORF(Outer Race Fault), IRF(Inner Race Fault)



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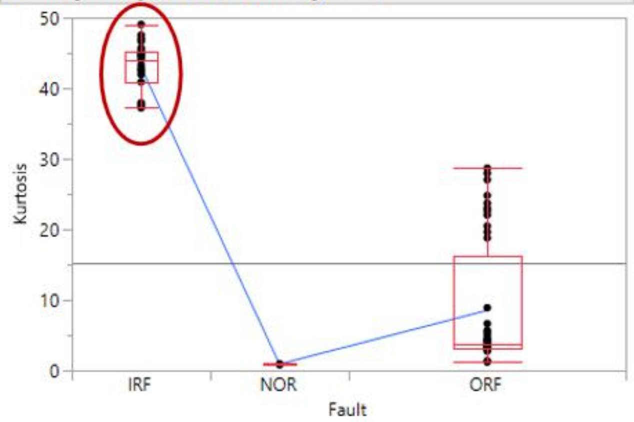
> NOR(Normal), ORF(Outer Race Fault), IRF(Inner Race Fault) ANOVA

> Skewness, Kurtosis 유의차 보임

Oneway Analysis of Kurtosis By Fault

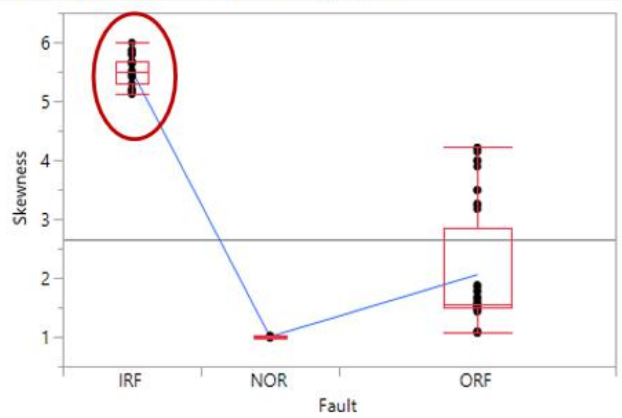


Oneway Anova

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Fault	2	38387.613	19193.8	416.0199	<.0001*
Error	141	6505.282	46.1		
C. Total	143	44892.895			

Oneway Analysis of Skewness By Fault



Oneway Anova

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Fault	2	419.64016	209.820	358.8497	<.0001*
Error	141	82.44296	0.585		
C. Total	143	502.08312			

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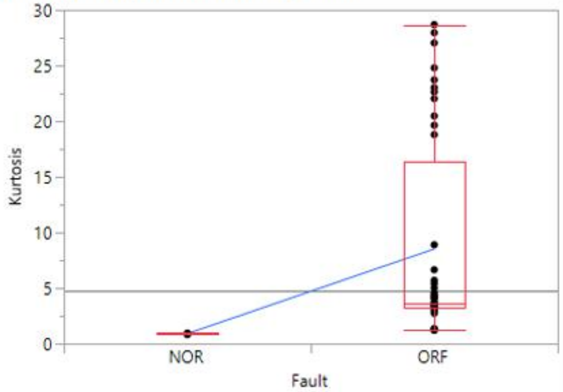
- 롤러베어링 가속도 신호에 절대값을 취하고 0.5초 단위로 에버리징

> NOR(Normal), ORF(Outer Race Fault), IRF(Inner Race Fault) ANOVA

> Skewness, Kurtosis 유의차 보임

Oneway Analysis of Kurtosis By Fault



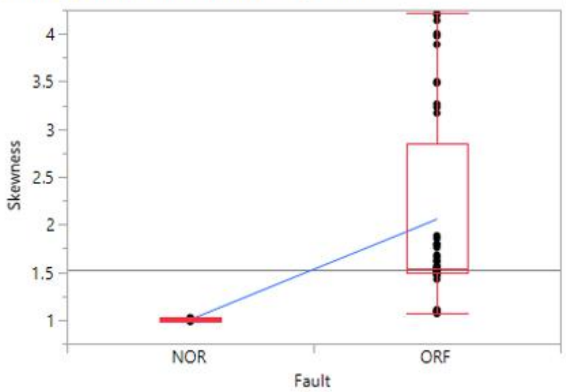
Oneway Anova

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Fault	1	2083.0641	2083.06	48.6109	<.0001*
Error	142	6084.9553	42.85		
C. Total	143	8168.0194			

Excluded Rows 72

Oneway Analysis of Skewness By Fault



Oneway Anova

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Fault	1	39.86537	39.8654	70.6392	<.0001*
Error	142	80.13799	0.5644		
C. Total	143	120.00336			

Excluded Rows 72

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롤러베어링 머신러닝 모델링

- Skewness, Kurtosis 값을 입력변수로 하여 NOR, ORF, IRF 고장 감지 모델링

  > 머신러닝: ANN(Artificial Neural Network), SVM(Support Vector Machines)

  > 로지스틱 회귀: NL(Nominal Logistics)

Model NTanH(3)NBoost(8)

Training — Fault

Measures	Value
Generalized RSquare	0.9999999
Entropy RSquare	0.9999995
RMSE	2.539e-6
Mean Abs Dev	5.8313e-7
Misclassification Rate	0
-LogLikelihood	8.3971e-5
Sum Freq	144

Confusion Matrix

Actual	Predicted Count		
Fault	IRF	NOR	ORF
IRF	48	0	0
NOR	0	48	0
ORF	0	0	48

Confusion Rates

Actual	Predicted Rate		
Fault	IRF	NOR	ORF
IRF	1.000	0.000	0.000
NOR	0.000	1.000	0.000
ORF	0.000	0.000	1.000

Validation — Fault

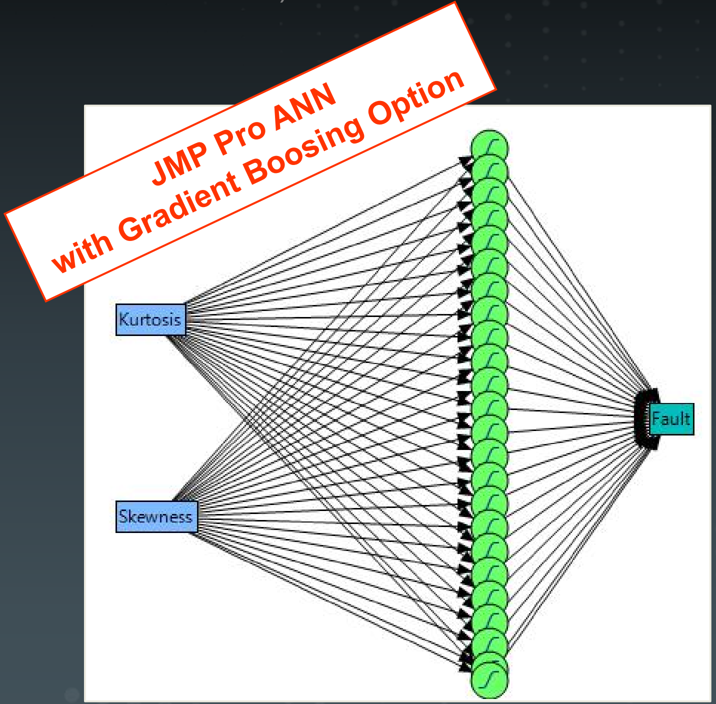
Measures	Value
Generalized RSquare	0.9999999
Entropy RSquare	0.9999997
RMSE	6.9591e-7
Mean Abs Dev	3.4609e-7
Misclassification Rate	0
-LogLikelihood	2.4919e-5
Sum Freq	72

Confusion Matrix

Actual	Predicted Count		
Fault	IRF	NOR	ORF
IRF	24	0	0
NOR	0	24	0
ORF	0	0	24

Confusion Rates

Actual	Predicted Rate		
Fault	IRF	NOR	ORF
IRF	1.000	0.000	0.000
NOR	0.000	1.000	0.000
ORF	0.000	0.000	1.000



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  - > 머신러닝: ANN(Artificial Neural Network), SVM(Support Vector Machines)
  - > 로지스틱 회귀: NL(Nominal Logistics)

Support Vector Machine Model 1

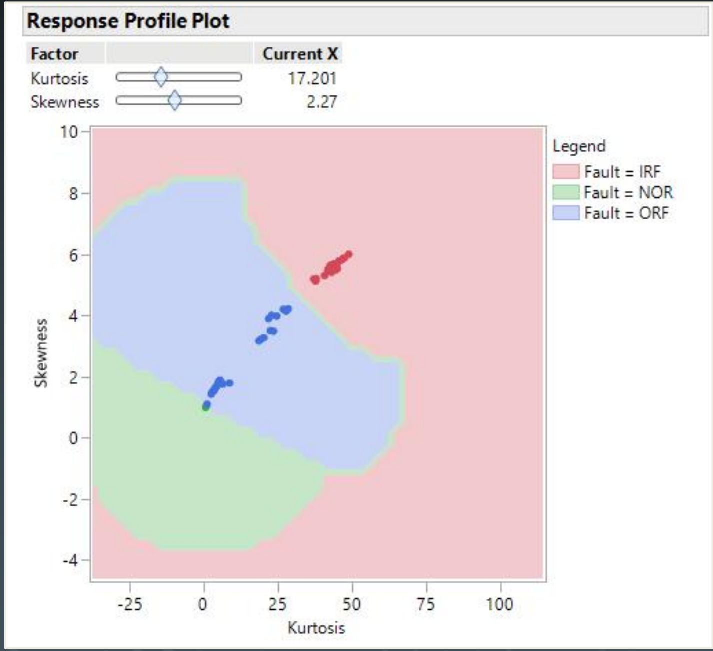
Confusion Matrix

Training

Actual Fault	Predicted Rate IRF	NOR	ORF
IRF	1.000	0.000	0.000
NOR	0.000	1.000	0.000
ORF	0.000	0.000	1.000

Misclassification Rate: 0.0000

Actual Fault	Predicted Count IRF	NOR	ORF
IRF	72	0	0
NOR	0	72	0
ORF	0	0	72



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  > 머신러닝: ANN(Artificial Neural Network), SVM(Support Vector Machines)
  > 로지스틱 회귀: NL(Nominal Logistics), GR(Generalized Regression)

Nominal Logistic Fit for Fault

Converged in Gradient, 23 iterations

Confusion Matrix

Training

Actual	Predicted Count		
Fault	IRF	NOR	ORF
IRF	72	0	0
NOR	0	72	0
ORF	0	0	72

[추가] Generalized Regression

Multinomial Maximum Likelihood

Confusion Matrix

Training

Actual	Predicted Rate		
Fault	IRF	NOR	ORF
IRF	1.000	0.000	0.000
NOR	0.000	1.000	0.000
ORF	0.000	0.000	1.000

Misclassification Rate: 0.0000

Actual	Predicted Count		
Fault	IRF	NOR	ORF
IRF	72	0	0
NOR	0	72	0
ORF	0	0	72

JMP PRO

Multinomial Lasso with AICc Validation

Confusion Matrix

Training

Actual	Predicted Rate		
Fault	IRF	NOR	ORF
IRF	1.000	0.000	0.000
NOR	0.000	1.000	0.000
ORF	0.000	0.000	1.000

Misclassification Rate: 0.0000

Actual	Predicted Count		
Fault	IRF	NOR	ORF
IRF	72	0	0
NOR	0	72	0
ORF	0	0	72

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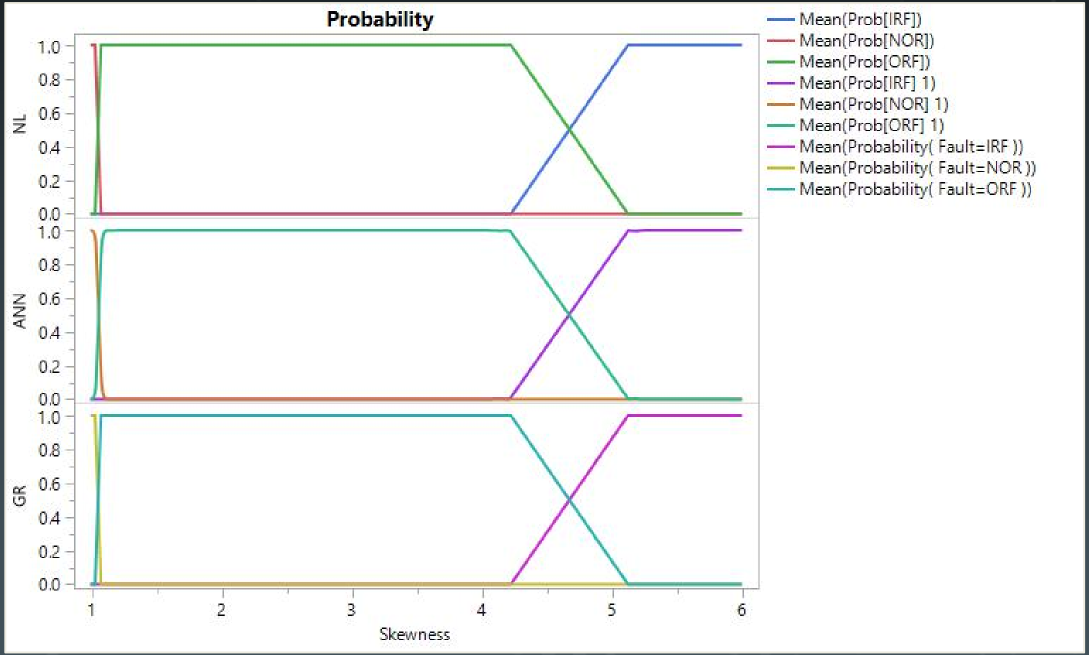

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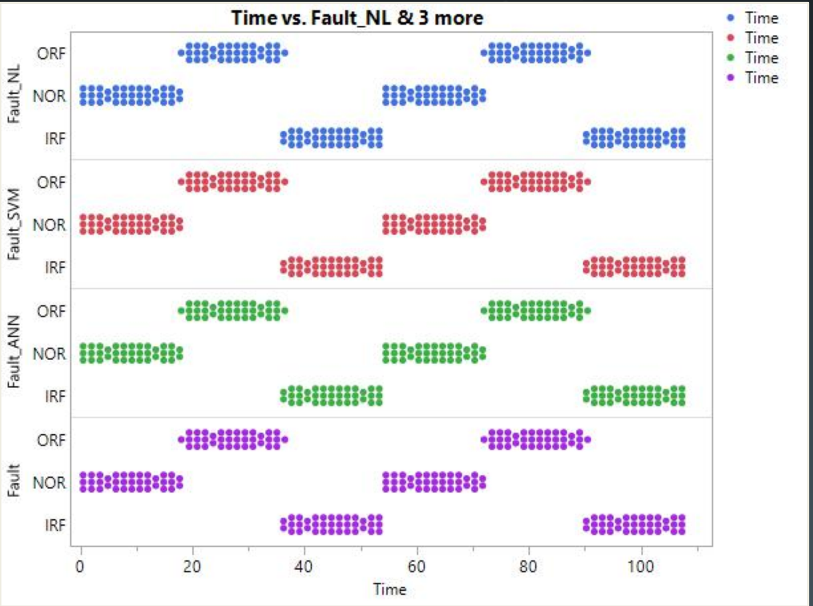
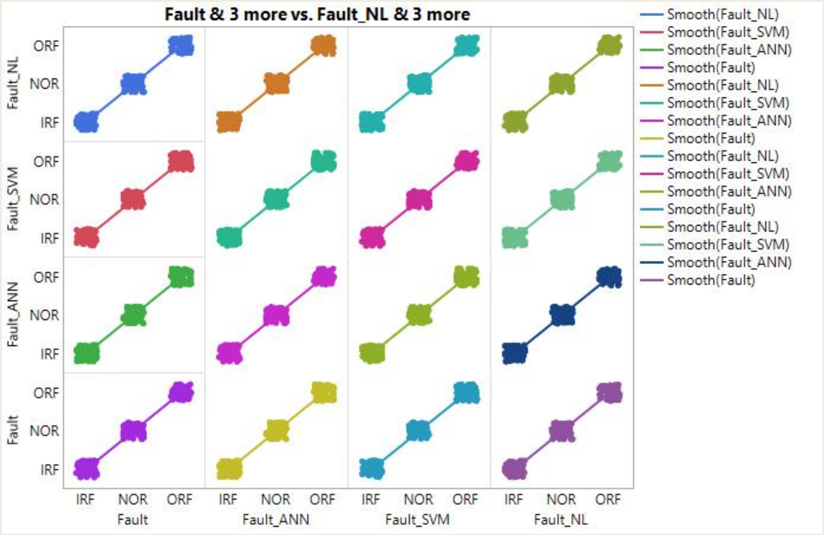
롤러베어링 머신러닝 모델링 검증

- 학습 데이터(Fault)를 100% 학습(Fault_ANN, Fault_SVM, Fault_NL)

  > 학습 데이터 Fault를 Fault_ANN, Fault_SVM, Fault_NL 3가지 모델 모두 100% 예측 확인





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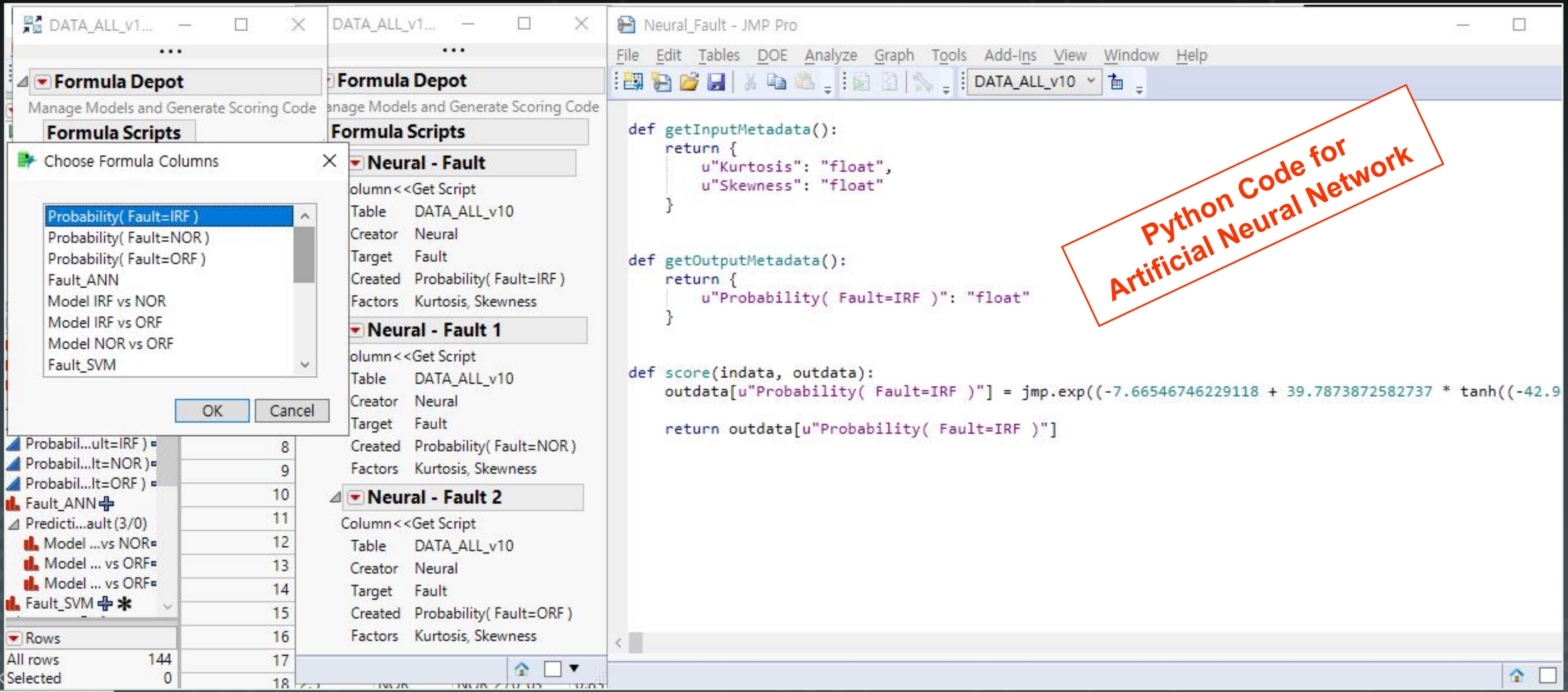
▪ 롤러베어링 머신러닝 이상 감지 모니터링 시스템 구축

- 고장 진단 모델링 수식을 JMP Pro의 Python Code Genertion을 적용하여 모니터링 시스템 구축



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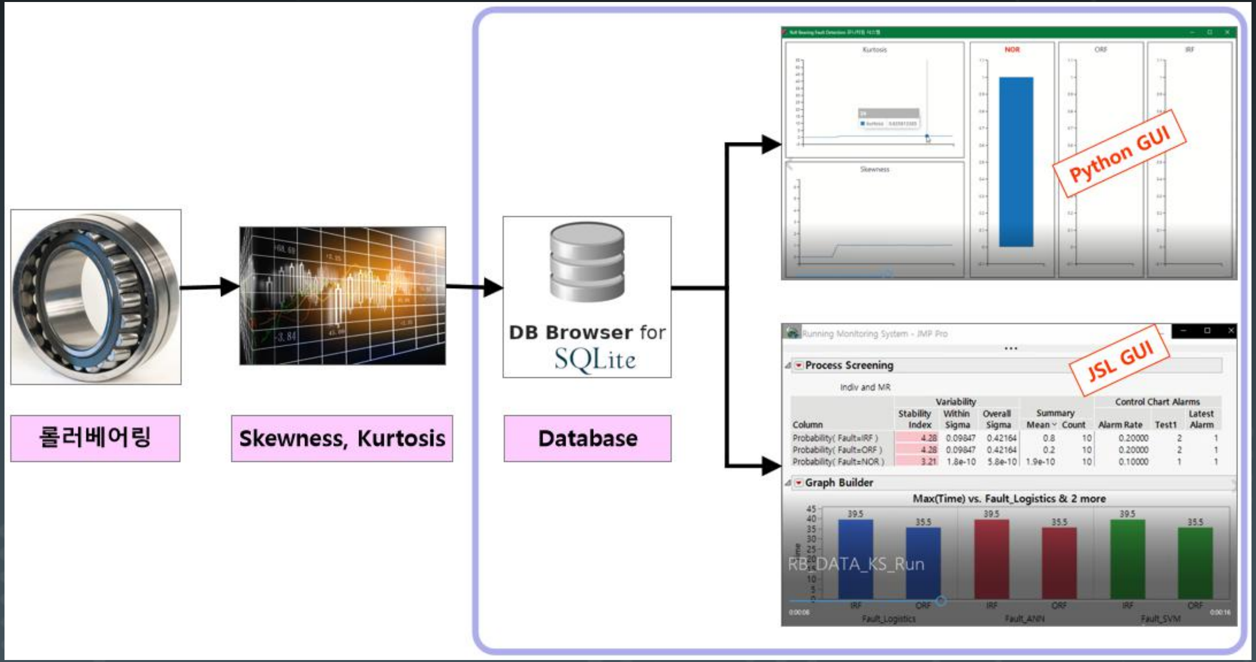
롤러베어링 머신러닝 이상 감지 모니터링 시스템 구축

- RB_DATA_KS.db: time, Skewness, Kurtosis 입력 데이터 데이터베이스
- RB_Neural_Fault_Eqn.py: 신경망 고장 감지 수식
- Python GUI 구축(JSL GUI 구축)



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롤러베어링 머신러닝 이상 감지 모니터링 시스템 구축

- 데모
  > JSL 데모

  > Python 데모

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