NIST
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Korea's Efforts towards PHM in Semiconductor and Automotive Manufacturing

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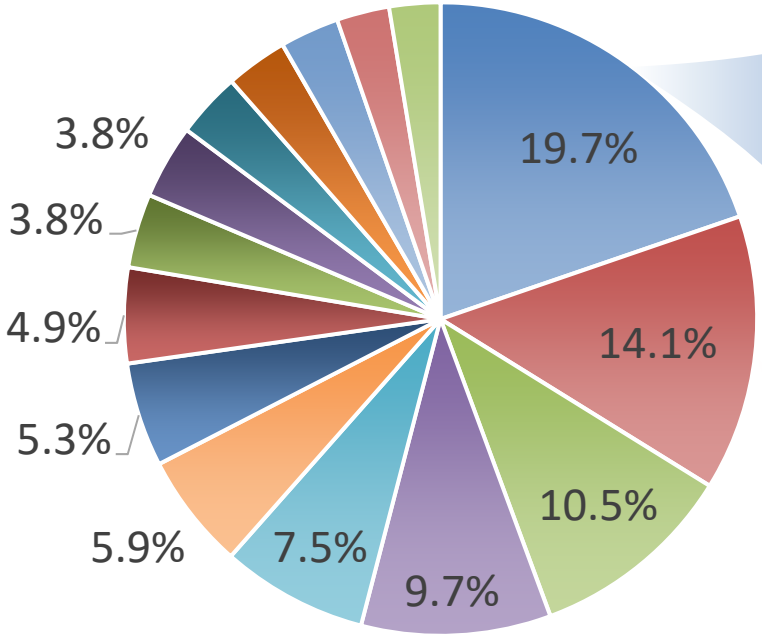
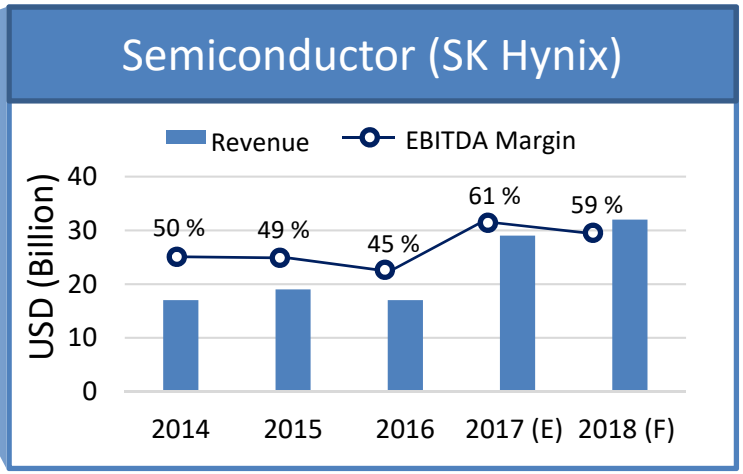
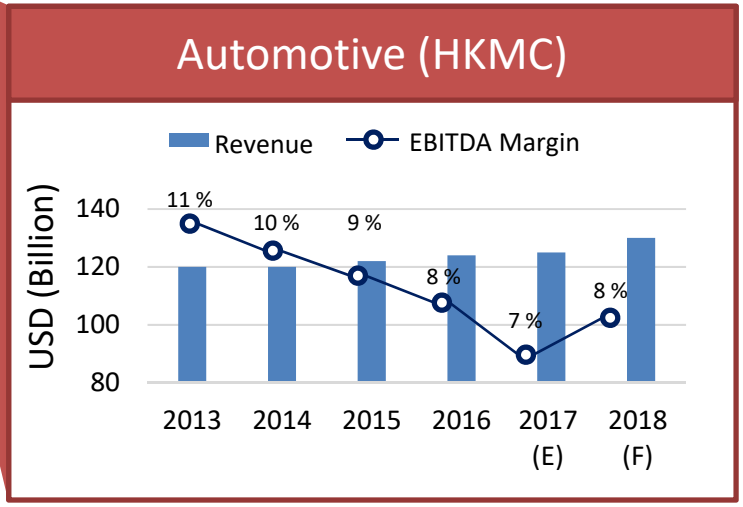
Gwangju Institute of Science and Technology

Major Export Products from Korea



No. 1: Semiconductor
No. 2: Automotive
No. 3: Petrochemicals
No. 4: Shipbuilding
No. 5: Oil refinery
⋮

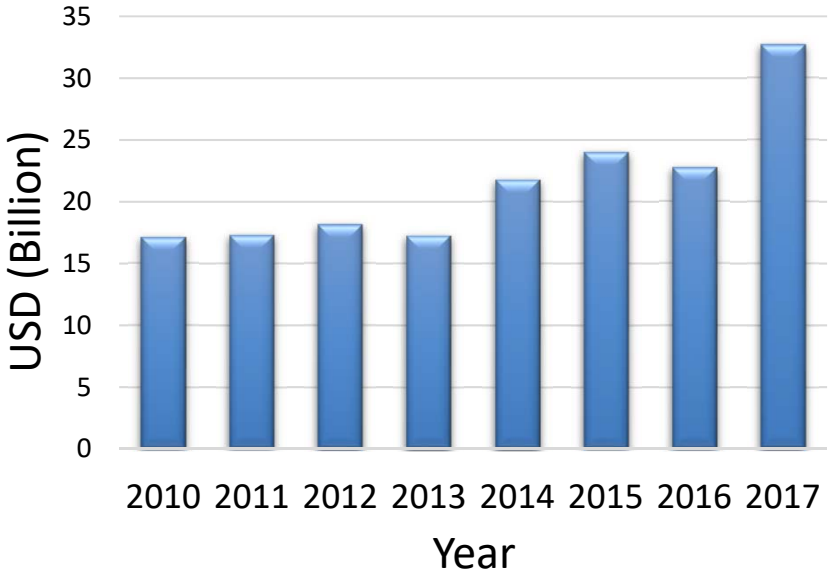




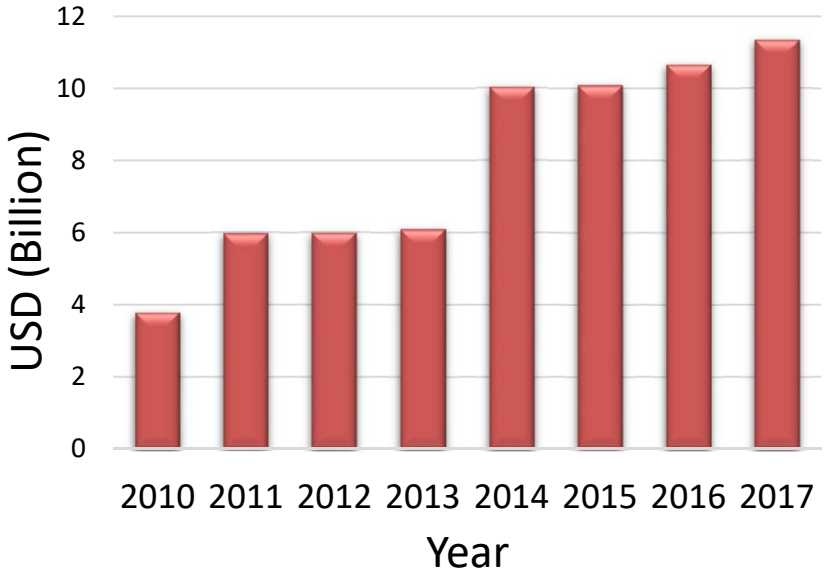
www.kiet.re.kr/kiet_web/index.jsp?sub_num=73&state=view&idx=53997
www.rating.co.kr/main.do

Manufacturing Facility Investment

- Capital investment is steadily increasing.
  - Significant capital investment In semiconductor equipment took place in 2017.
  - Major increases in automotive equipment took place in 2011 and 2014.



Amount of investment in **semiconductor** industry



Amount of investment in **automotive** industry

http://www.kiet.re.kr/kiet_web/?sub_num=73&state=view&idx=53997

Loss by Unscheduled Downtime

- A loss of 60k wafers due to a 30 minute power outage in 2018 resulted in a loss of approximately US$ 46 million.
- A production loss of 120 vehicles occurred due to 2 hours of power outage.

삼성전자 평택캠퍼스 반도체 생산라인(평택 1라인) 항공사진. 사진=삼성전자 제공.

현대자동차 울산 3공장

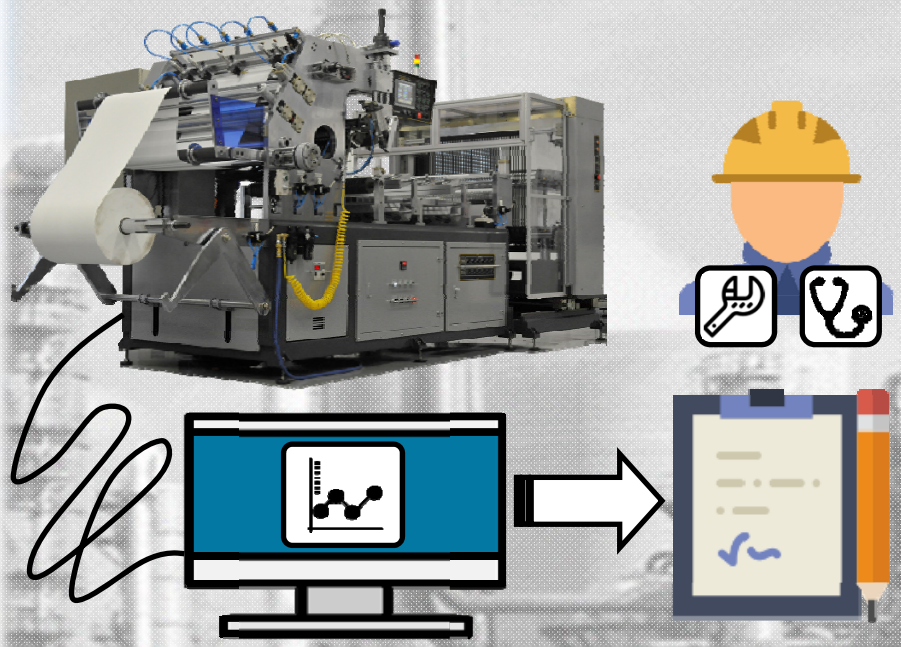
30 Min. → $ 46 Million

2 Hr. → $ 1 Million

plus.hankyung.com/apps/newsinside.view?aid=2018031521731&category=NEWSPAPER&sns=y
news.naver.com/main/read.nhn?mode=LSD&mid=sec&sid1=115&oid=214&aid=0000046774

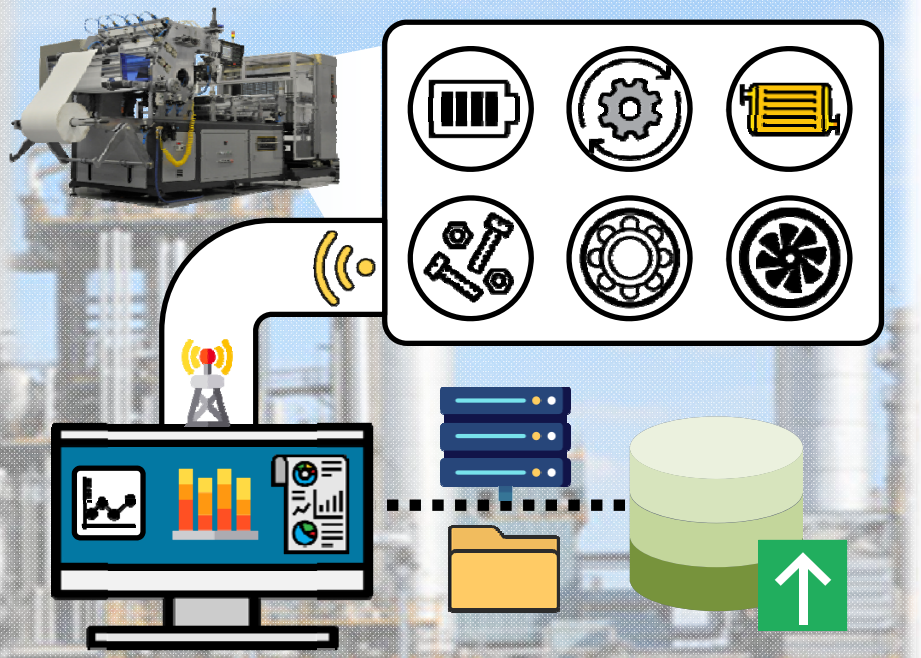
New Trend in PHM of Manufacturing Equipment

In the past



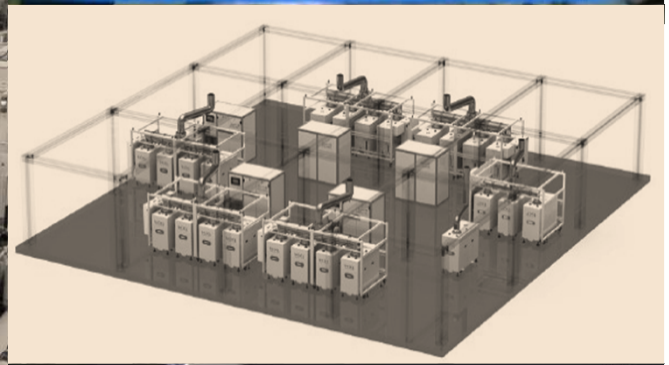
- Mission-Critical Equipment
- High Performance, High Cost Sensors
- Wired
- Manual inspection

New trend



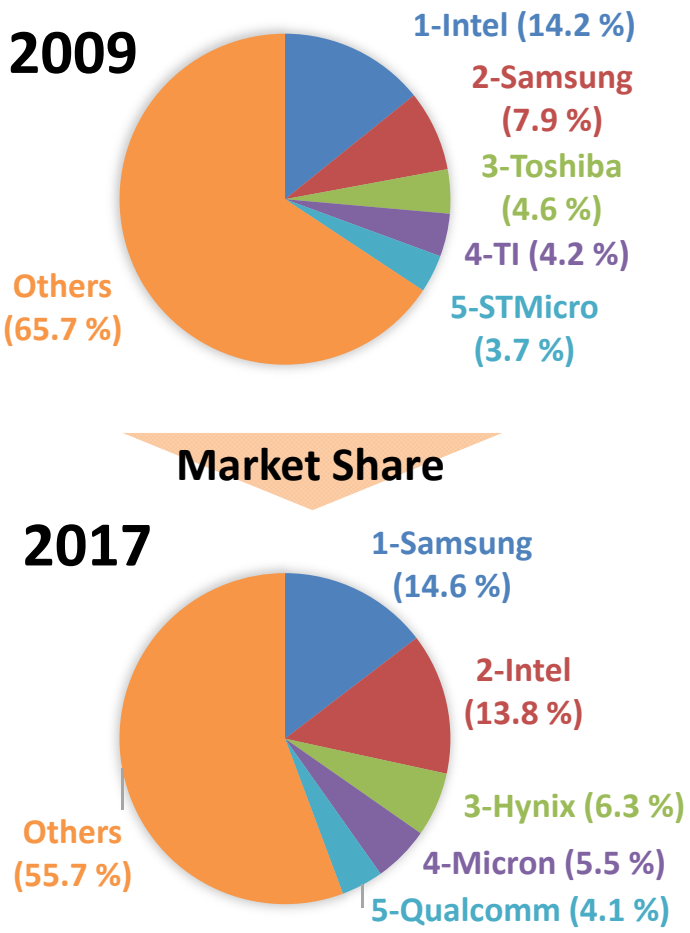
- Less Mission-Critical Equipment
- Satisfactory Performance, Low Cost Sensors
- Wireless
- Automatic Data Collection,
  Health Monitoring, Fault Diagnosis

PHM in Semiconductor Manufacturing

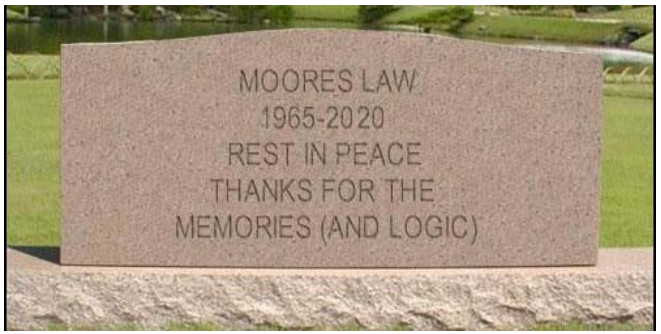


Why PHM in Semiconductor Manufacturing?

Endless competition



How to survive ?



- Fault Detection and Classification (FDC)
- Advanced Process Control (AEC)
- Advanced Equipment Control (APC)
- Chamber to Chamber Matching (C2C)
- Statistical Process Control
- Artificial Intelligence (AI)
- Integrated Metrology (IM)

⋮

Downtime Reduction by PHM Techniques

Example 1: Early detection of gas leakage

- Explosion or gas leakage can be prevented by real-time gas monitoring.
- If accidents occur, the loss can be up to 200 to 500 million US$.

Example 2: Lifetime extension of vacuum pumps

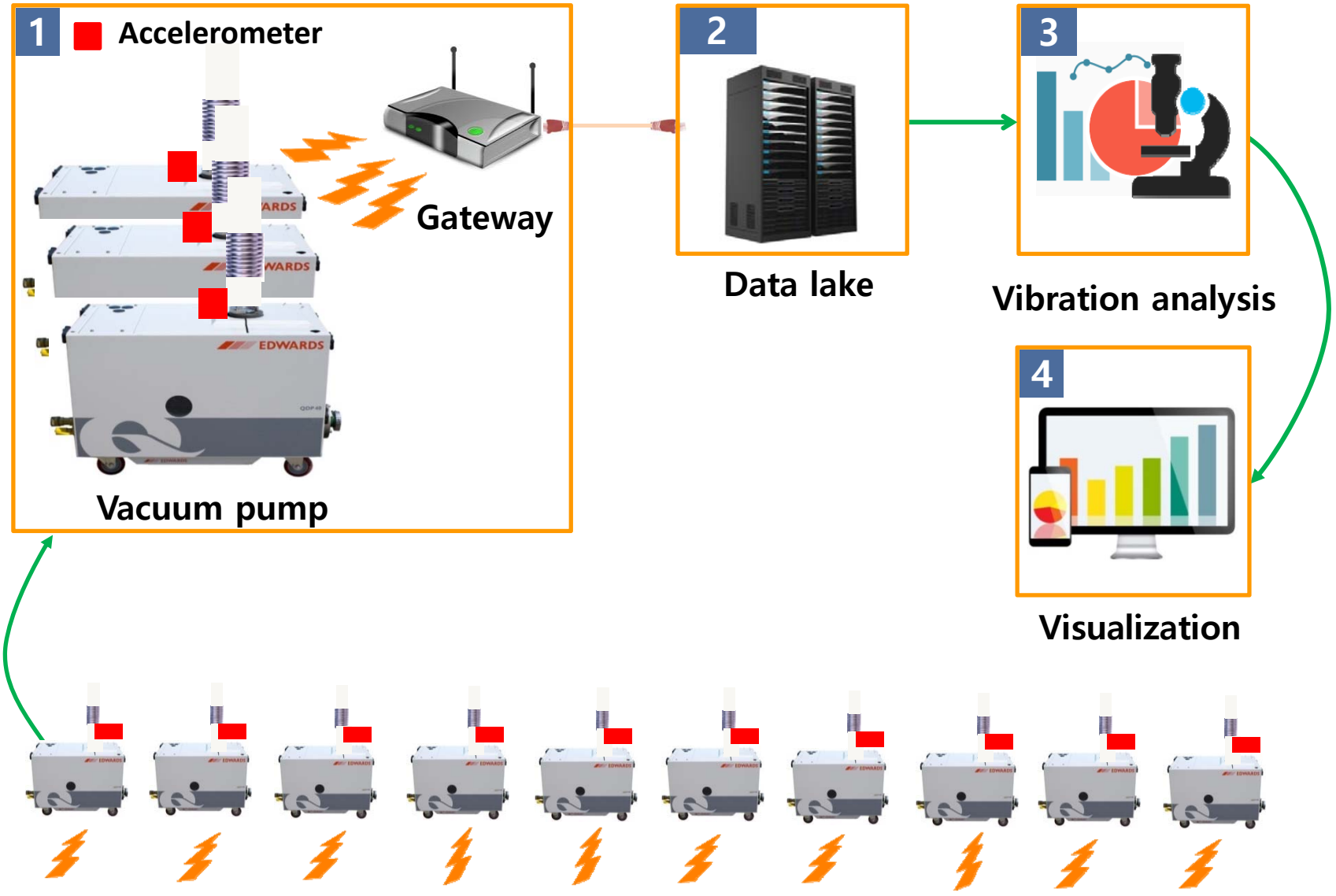
2000 pumps

$ 35,000

Extend life: 1 %

$ 0.7 M

Procedure for Vacuum Pump PHM



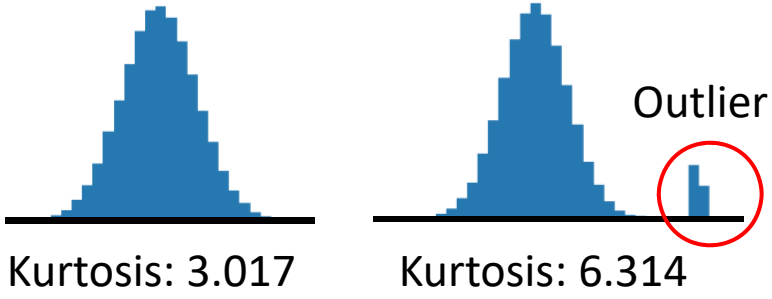
Feature Analysis for Condition Monitoring

Time domain

1. Vibration severity - RMS

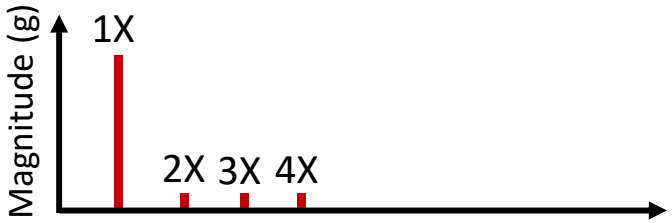
VIBRATION SEVERITY PER ISO 10816						
Machine			Class I small machines	Class II medium machines	Class III large rigid foundation	Class IV large soft foundation
	in/s	mm/s				
Vibration Velocity Vrms	0.01	0.28				
	0.02	0.45				
	0.03	0.71		good		
	0.04	1.12				
	0.07	1.80				
	0.11	2.80		satisfactory		
	0.18	4.50				
	0.28	7.10		unsatisfactory		
	0.44	11.2				
	0.70	18.0				
	0.71	28.0		unacceptable		
	1.10	45.0				

2. Vibration severity - Kurtosis

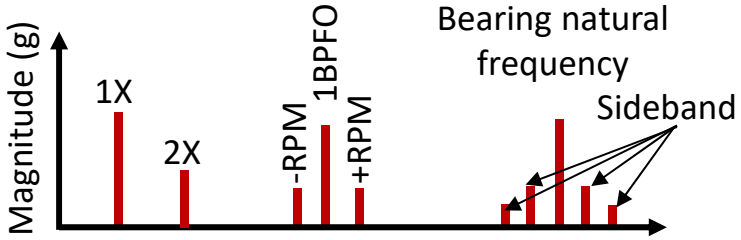


Frequency domain

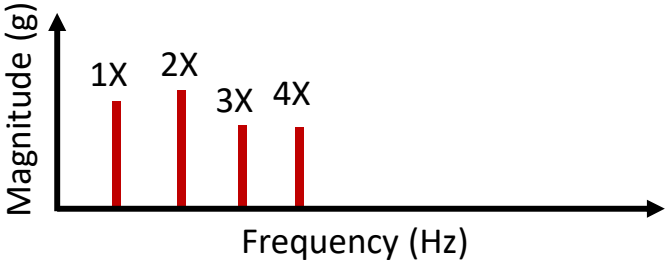
3. Unbalance



4. Bearing defect

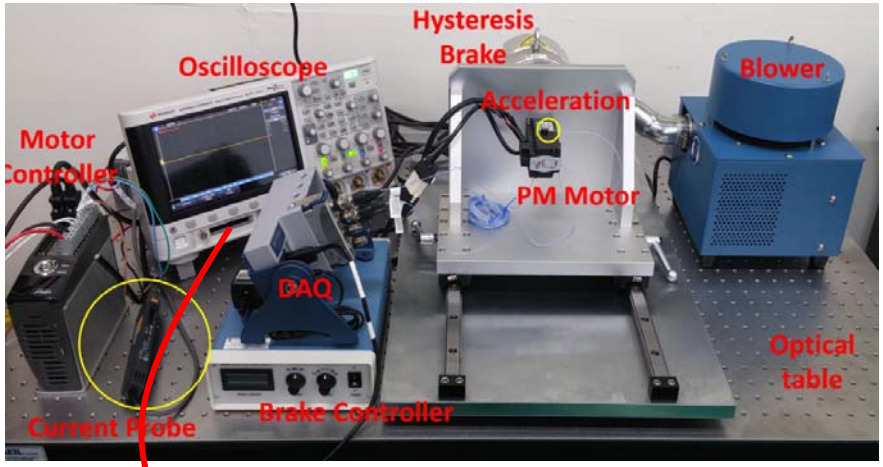


5. Looseness

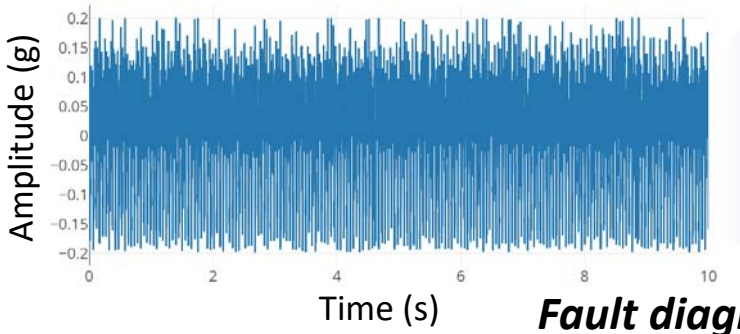


Validation Using Small Testbed Data

Small testbed



Vibration signal collected from accelerometers

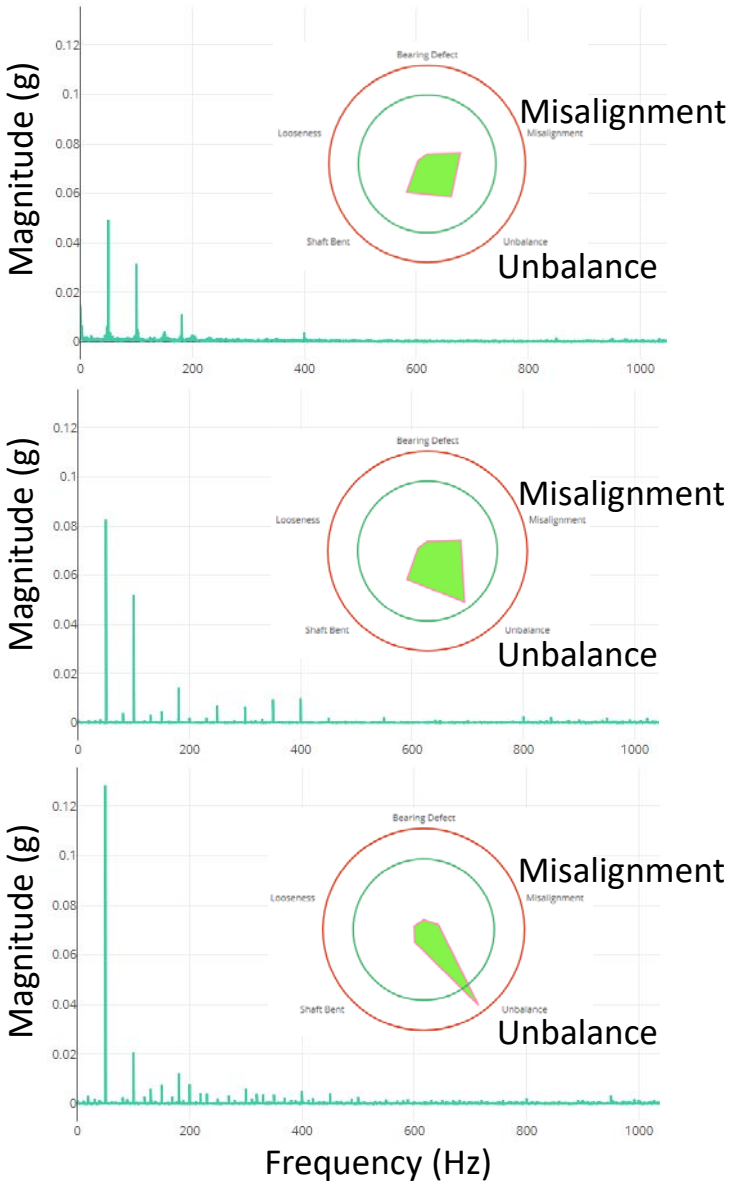


Fault diagnosis and visualization

Normal

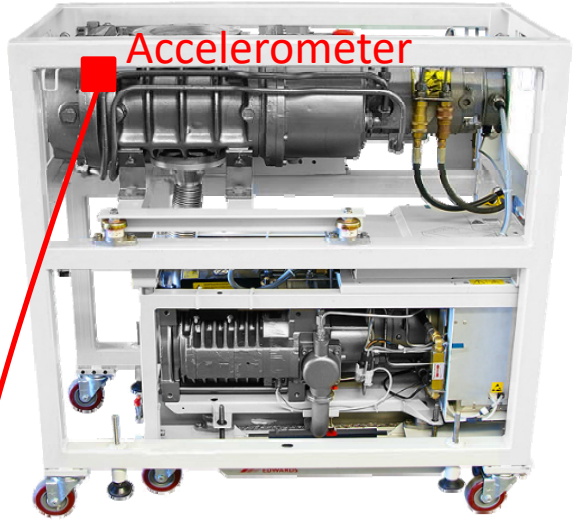
Unbalance 1

Unbalance 2

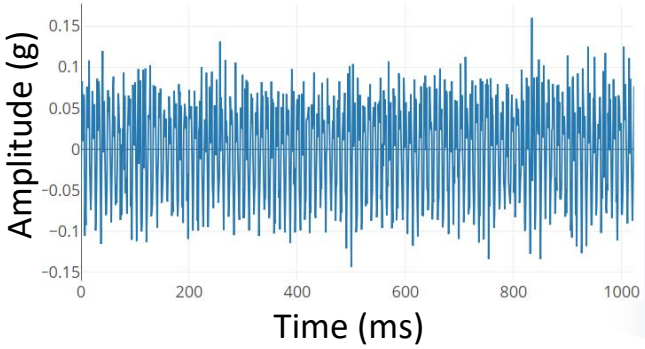


Validation Using Field Data

Vacuum pump in field

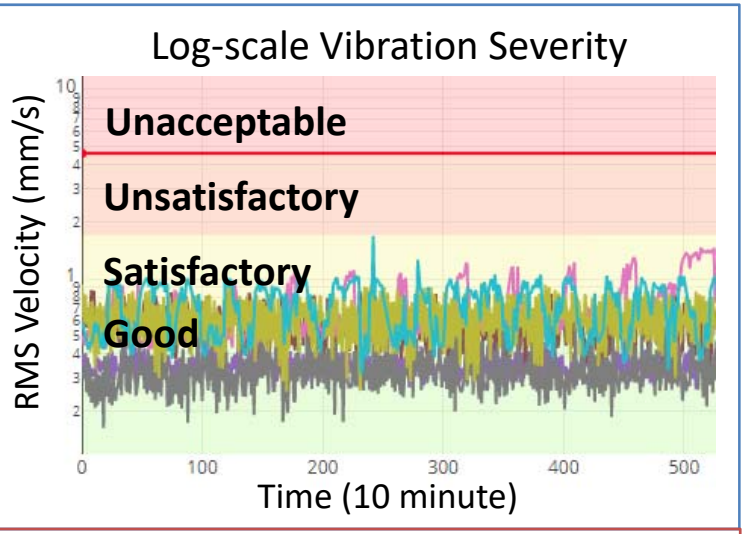


Vibration signal collected from accelerometer

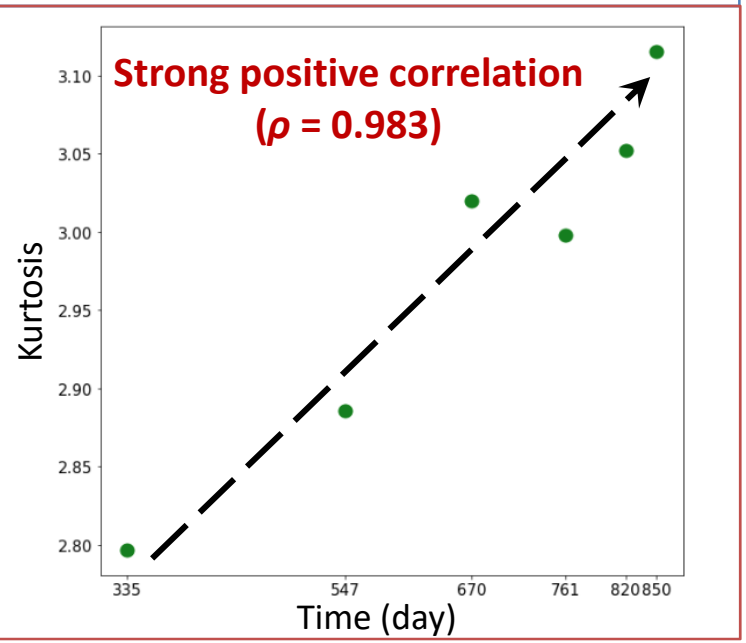


Condition monitoring – Vibration severity

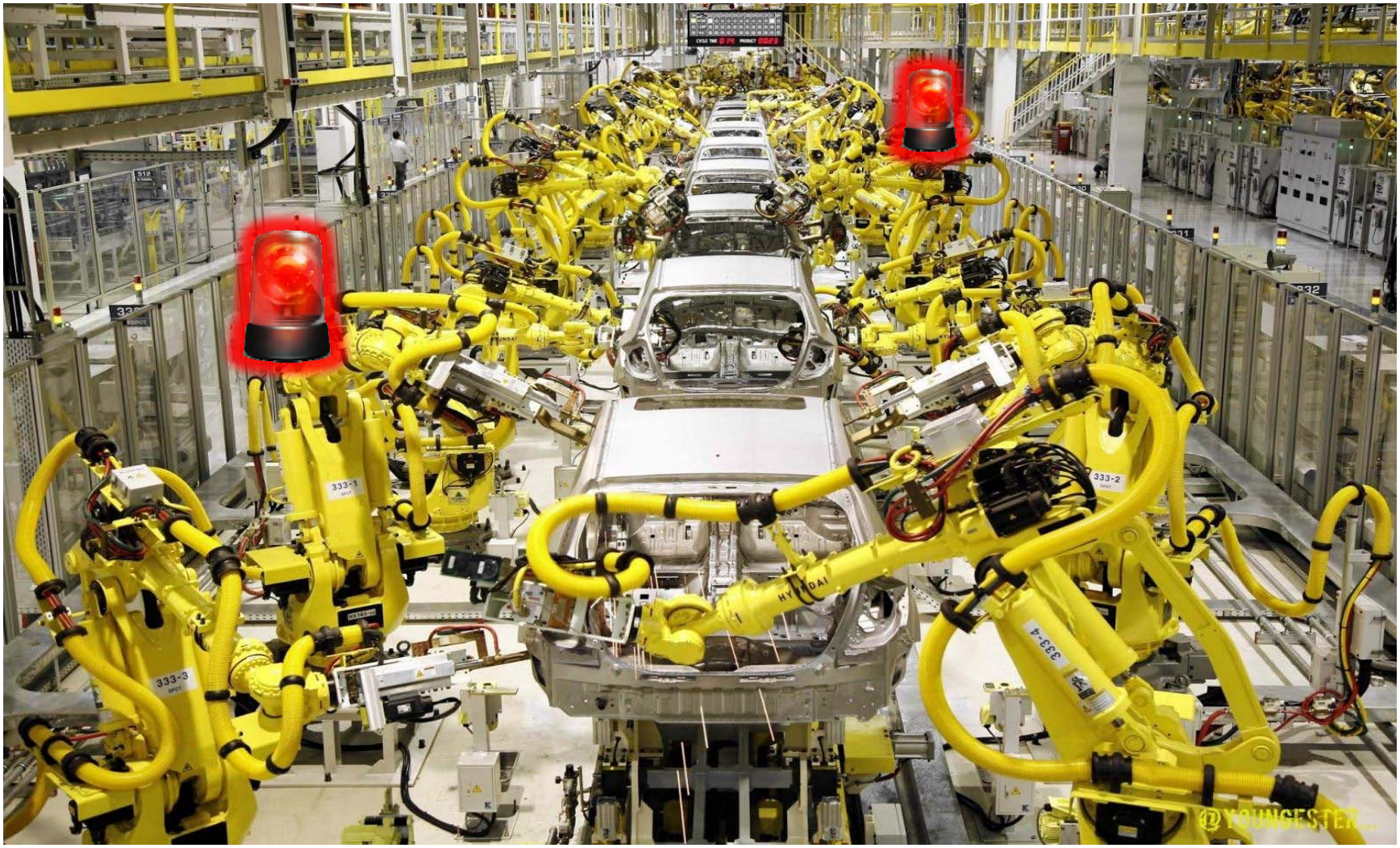
RMS



Kurtosis



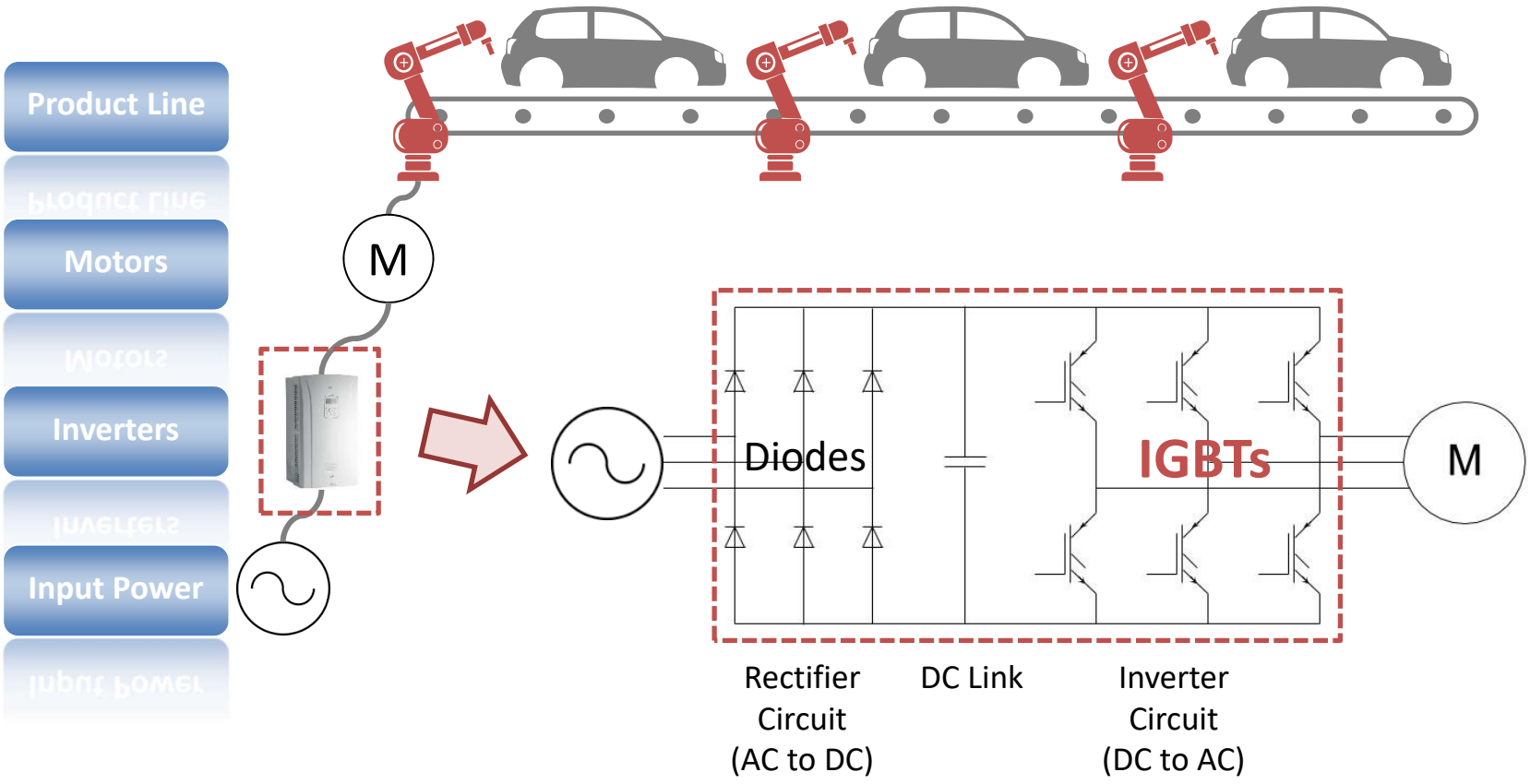
Inverter PHM in Automotive Manufacturing



J. Lee, H. Oh, C. H. Park, B. D. Youn, and B. Han, "Test Scheme and Degradation Model of Accumulated ESD Damage for IGBT Prognostics," IEEE Transactions on Power Electronics, submitted.

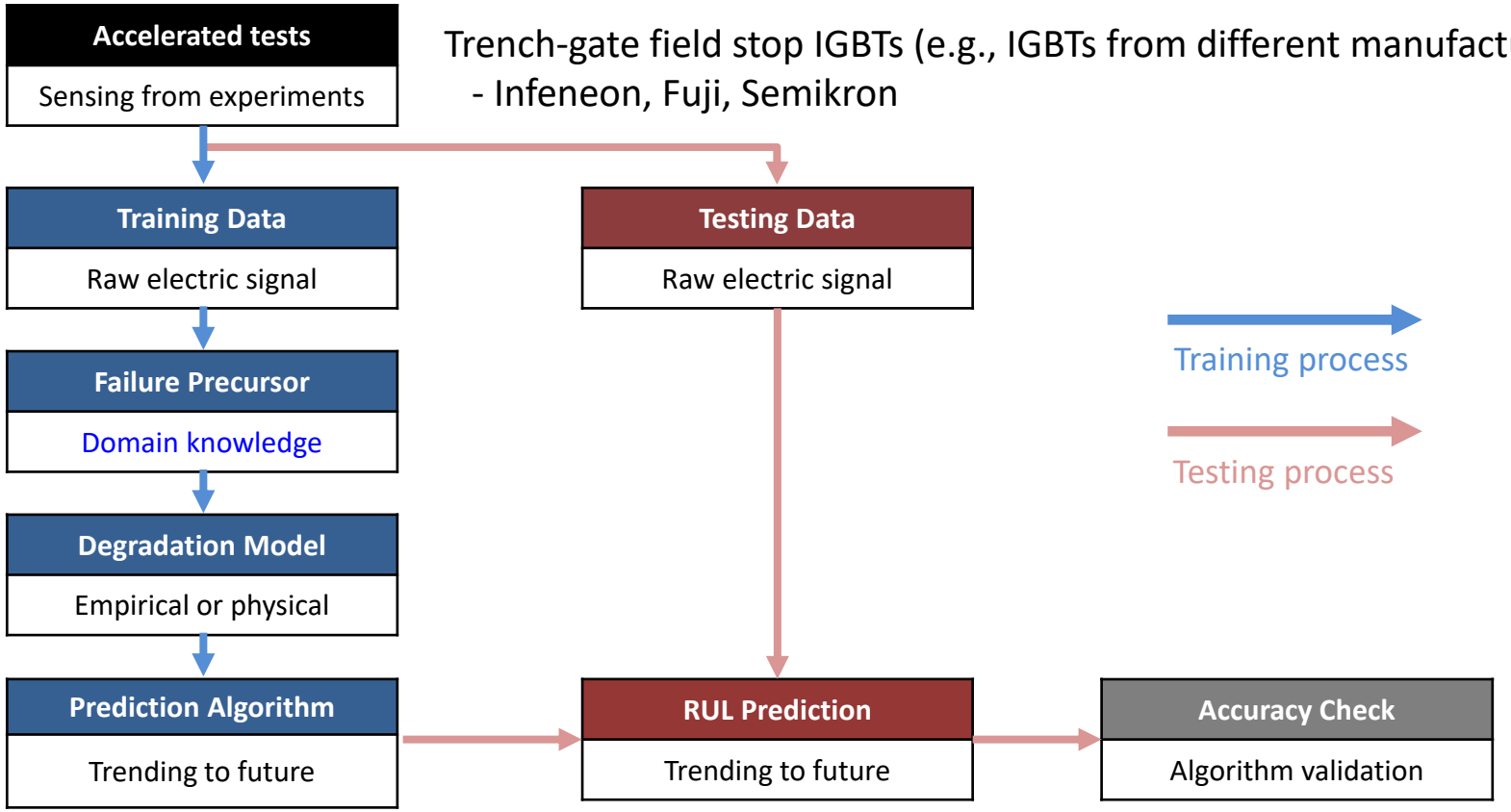
Downtime Reduction by Inverter PHM

- **Objective**
  - To develop degradation models of ESD damage for IGBTs prognostics

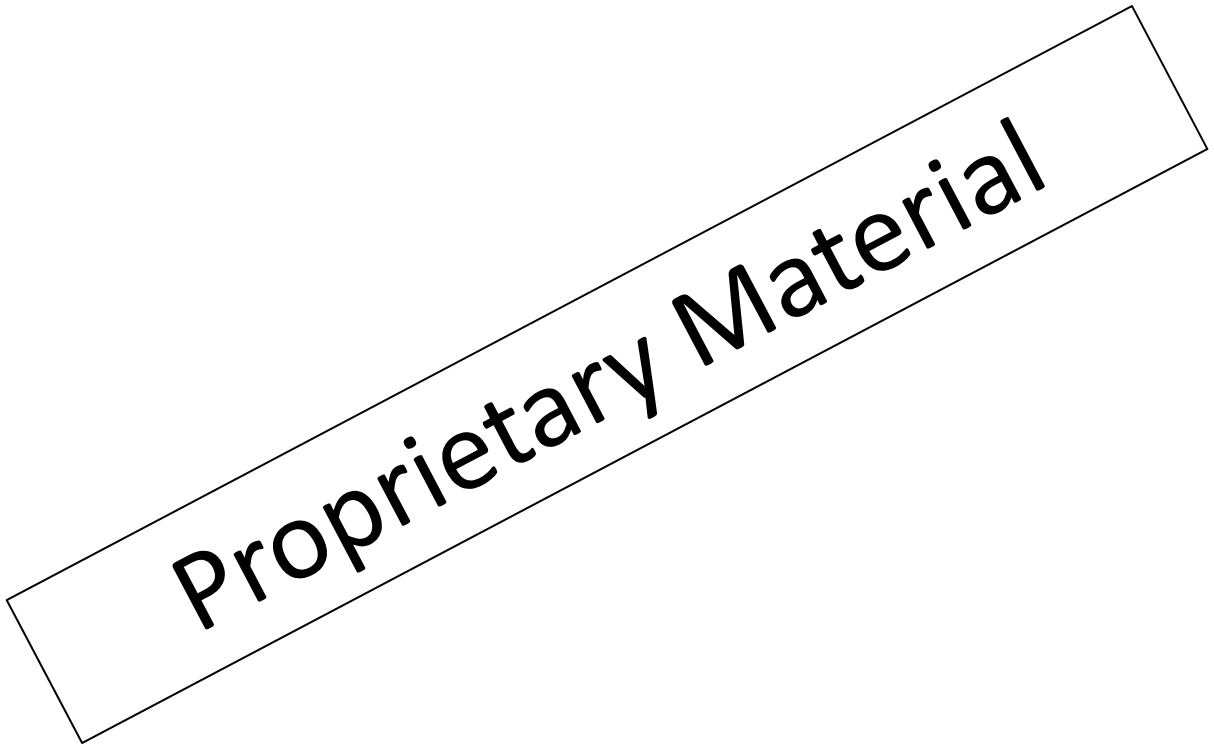


Procedures for Rotor PHM

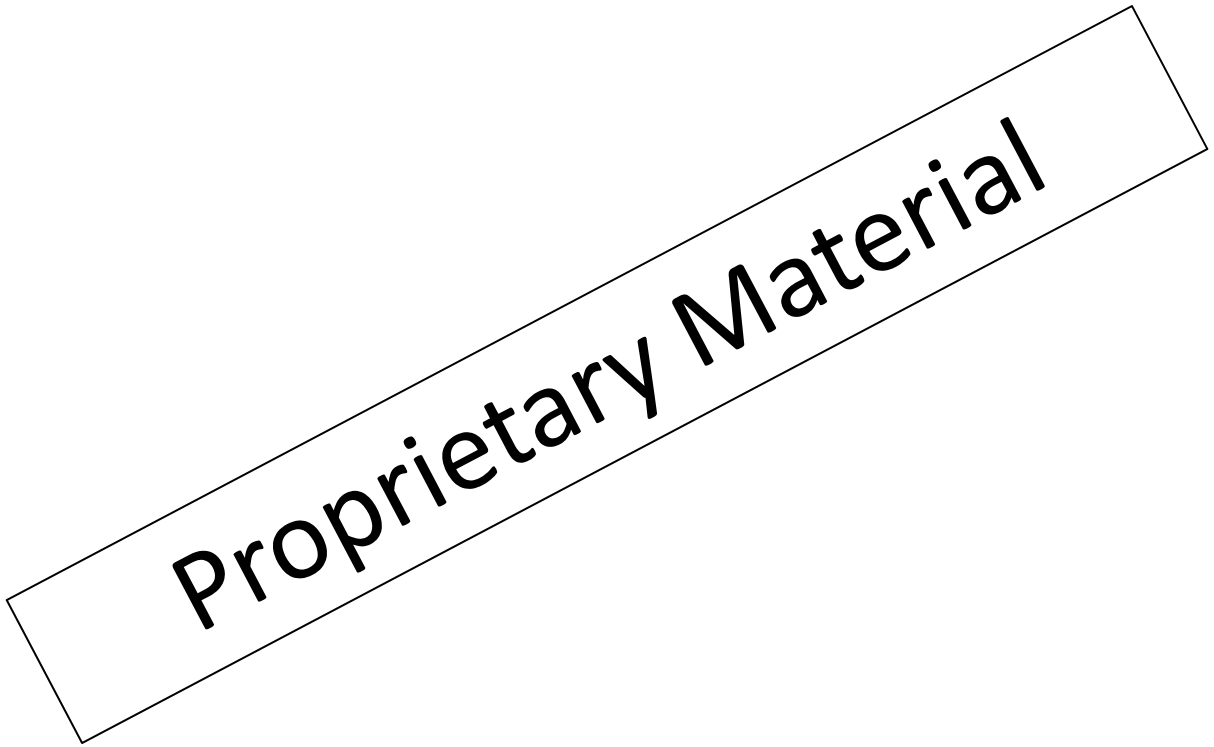
General Process for RUL Prediction



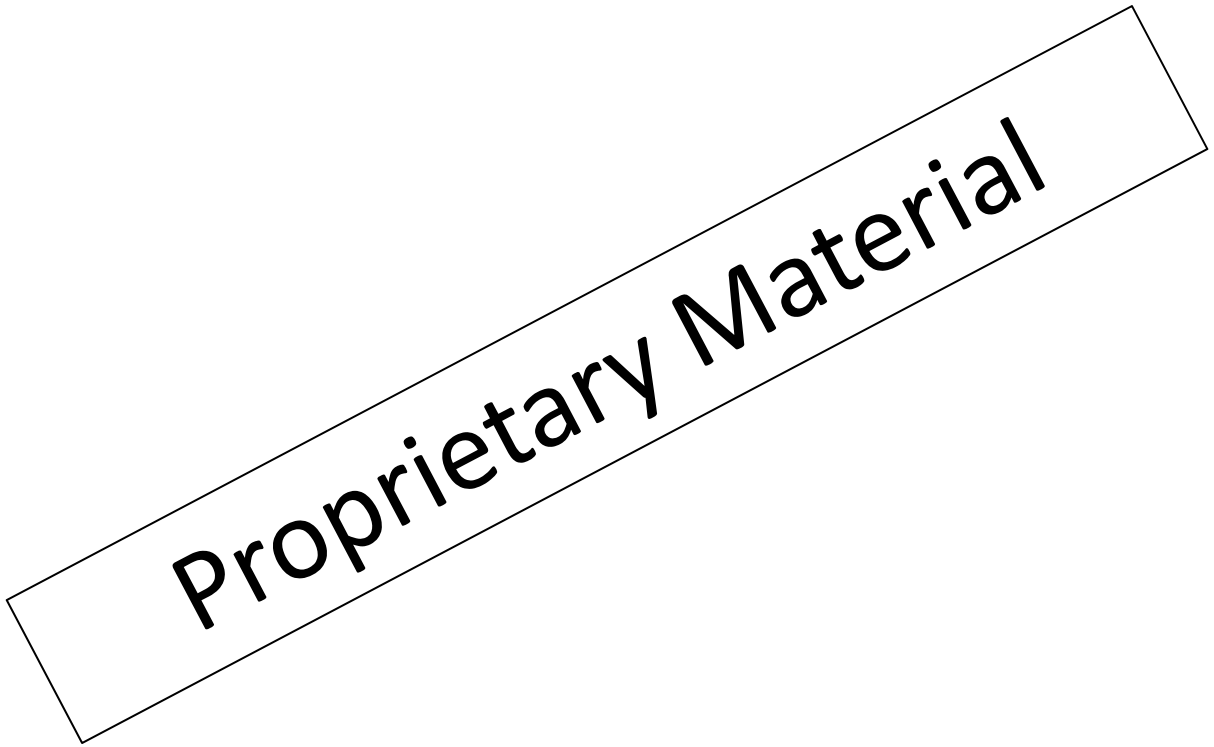
Degradation Testing



Failure Precursor



Degradation Modelling

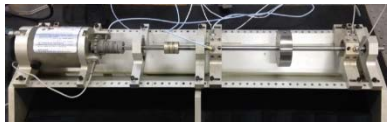


Rotor Bearing in Power Plant

H. Oh, J. H. Jung, B. Jeon, and B. D. Youn, "Scalable and Unsupervised Feature Engineering Using Vibration-Imaging and Deep Learning for Rotor System Diagnosis," *IEEE Transactions on Industrial Electronics*, Vol. 65, pp. 3539-3549, March 2018.
(SCI, Impact factor: 7.168, 0.85%)

Scalable Feature Engineering

Test-bed



Scale Up

Power Plant

***Deep Learning**

- High performance in generalization
- Exclusion of feature selection
- Excellence in image recognition

Test-bed

Normal
Misalign.
Rubbing
Oil whirl

Power Plant

Normal
Misalign.
Oil whirl

Unknown conditions

Require semi-supervised learning algorithm.

Simple System ⟺ **Complex System**

Require algorithm that can generalize the features from complex systems.

Small Data ⟺ **Big Data**

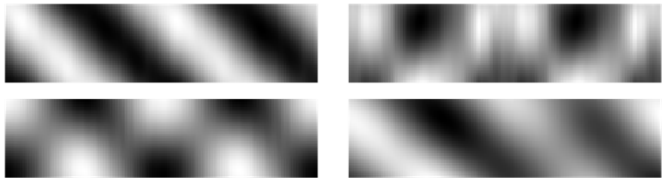
Require algorithm that can process large amount of data.

Proposed Scheme for Rotor System Diagnosis

Vibration Image Generation

RK4 test-bed (Labeled)
Power plant (Labeled)

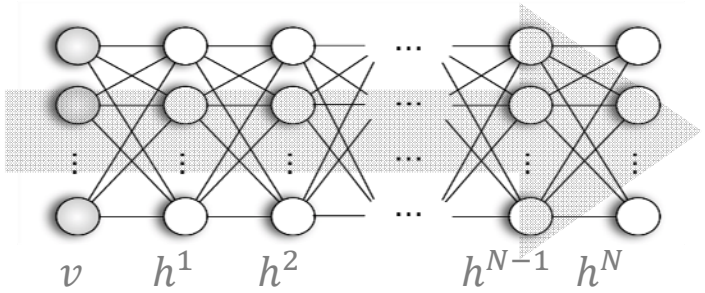
Power plant (Unlabeled)



Vibration images using ODR

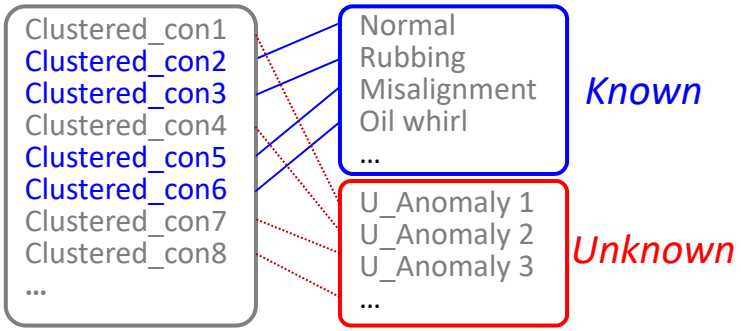
High-level Feature Abstraction

- Greedy Layer-wise unsupervised pretraining: restricted Boltzmann machine in deep belief network (DBN)

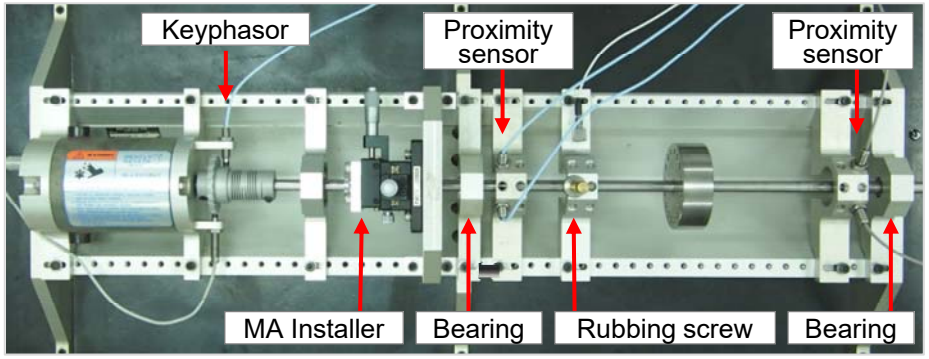


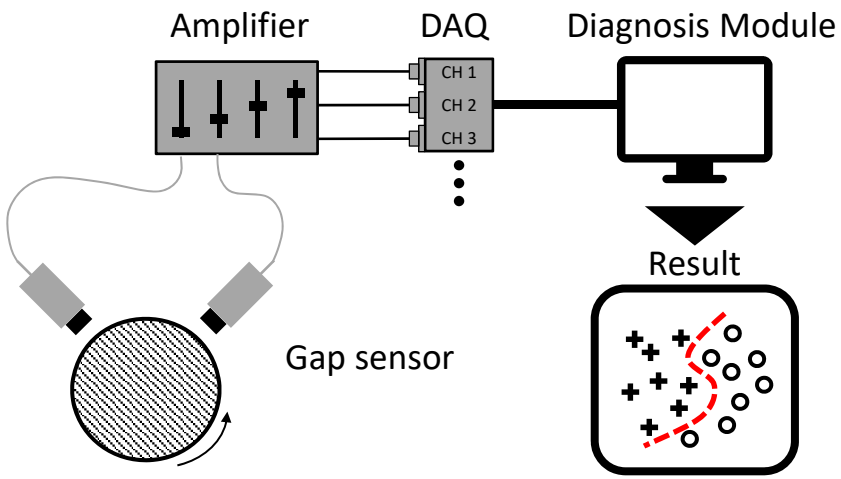
Health Reasoning

- Classification: multi-layer perceptron (MLP)
- Clustering: self-organizing map



Data from RK4 Testbed and Real Power Plant

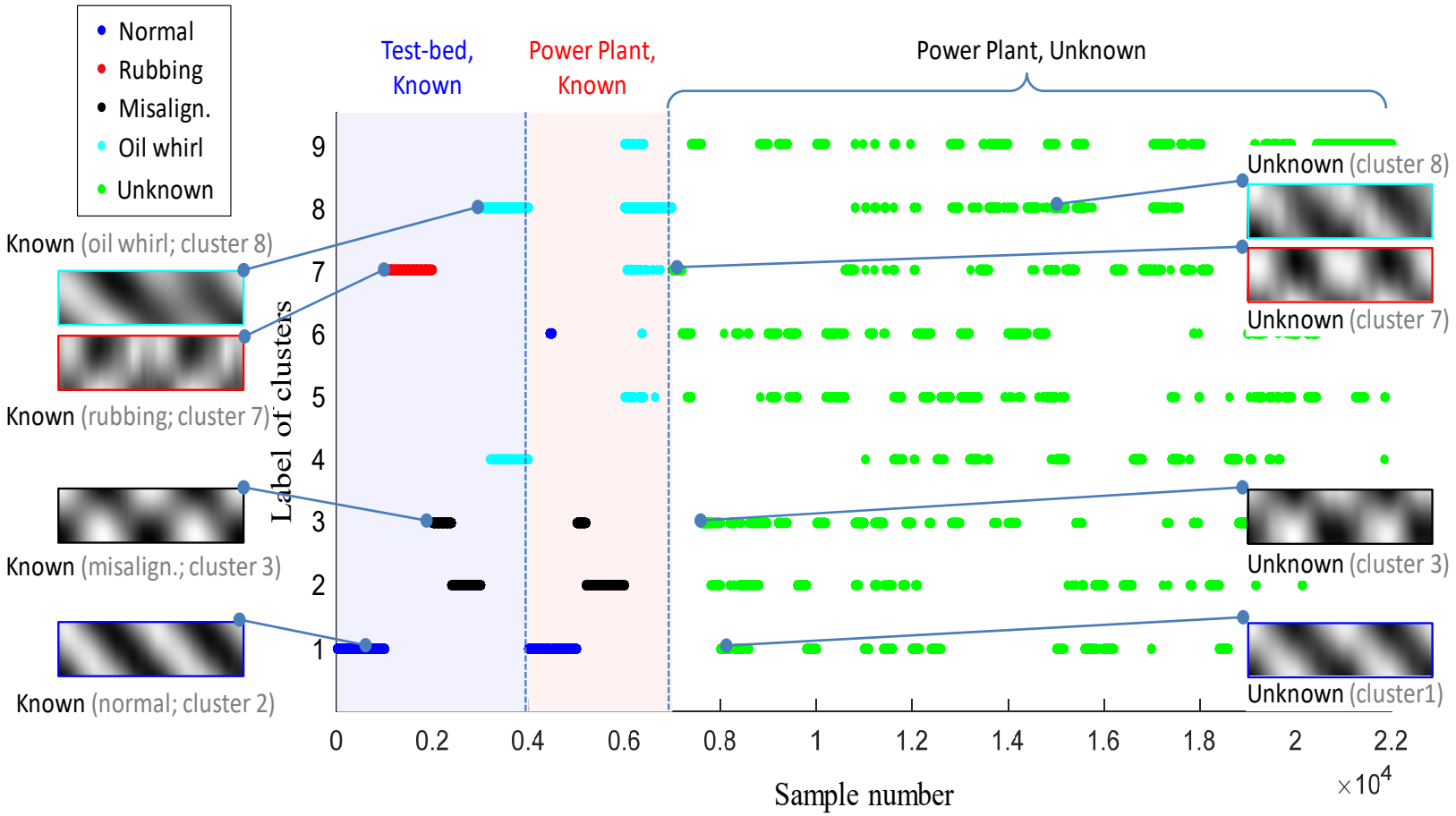
System (RK4 rotor kit, GE)	Data Configuration	Health Conditions
	8,500 samp./sec	Normal
	Vibration Data(4ch)	Rubbing
	Keyphasor Data	Misalignment
	3,600 rpm	Oil whirl



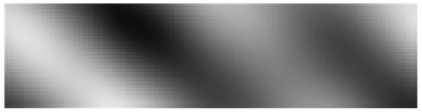
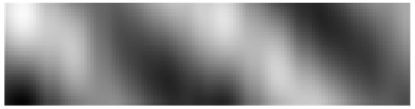
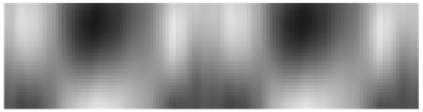
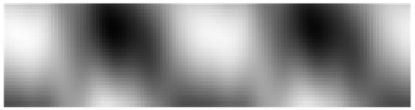
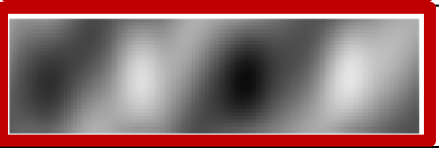
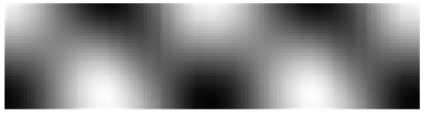
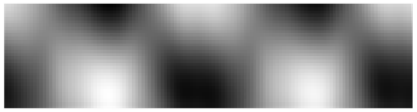
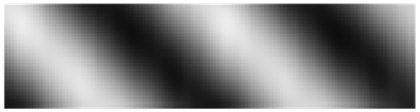
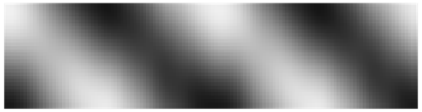
System	Status	Health condition	Number of image
Testbed	Labeled	Normal	1000
		Rubbing	1000
		Misalignment	1000
		Oil whirl	1000
Power plant	Labeled	Normal	1000
		Misalignment	1000
		Oil whirl	1000
	Unlabeled	Unknown	15000

Fault Diagnosis of Power Plant Journal Bearing

- Training data: 4000 images (testbed) + 3000 images (power plant)
- Test data: 15000 images (power plant)



Vibration Images from Testbed and Real Plant

	Testbed	Real plant
Unknown (Cluster 9)	N/A	
Oil whirl		
Rubbing		
Unknown (Cluster 6)	N/A	
Unknown (Cluster 5)	N/A	
Misalignment		
Normal		

Summary

- Korea's efforts towards PHM in semiconductor and automotive manufacturing were presented with two case studies.
  - Example 1: PHM in semiconductor manufacturing to reduce maintenance costs and prevent potential losses.
  - Example 2: PHM in automotive manufacturing to prevent unexpected failure and reduce downtime.
- Deep learning techniques can help to resolve scalability problems of PHM techniques.