Deep Learning based Diagnostics for Rotating Machinery on Orbit Analysis

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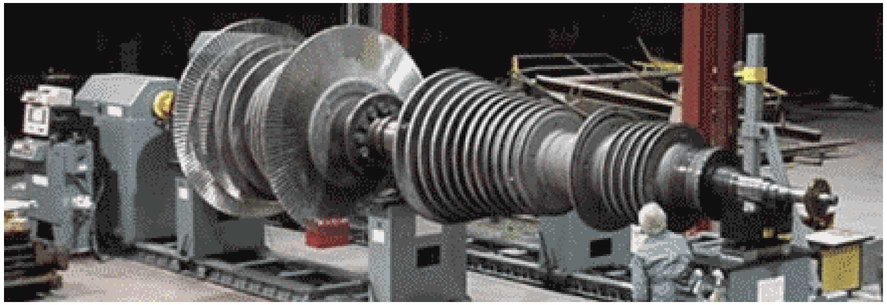
- Orbit Analysis for Rotating Machinery
- Deep Learning
- Pre-processing Steps
- Experimental Results
- Conclusions

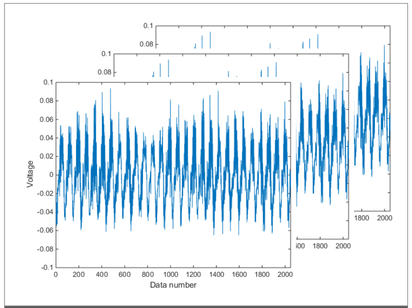
Rotating Machinery

- Mechanical component
- Key components to generate electric power (in power plants)
- Performance degradation and entire system break downs
  - Plant operation/maintenance cost
  - Level of safety

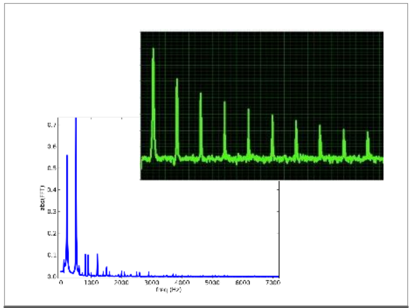


Monitoring Systems

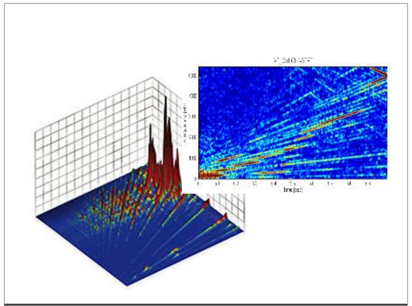
- Prognostics and Health Management (PHM) approach
- Prevent/Predict system failures



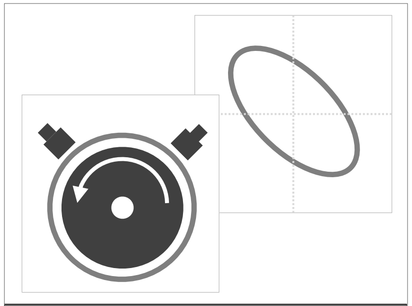
Time Domain



Frequency Domain



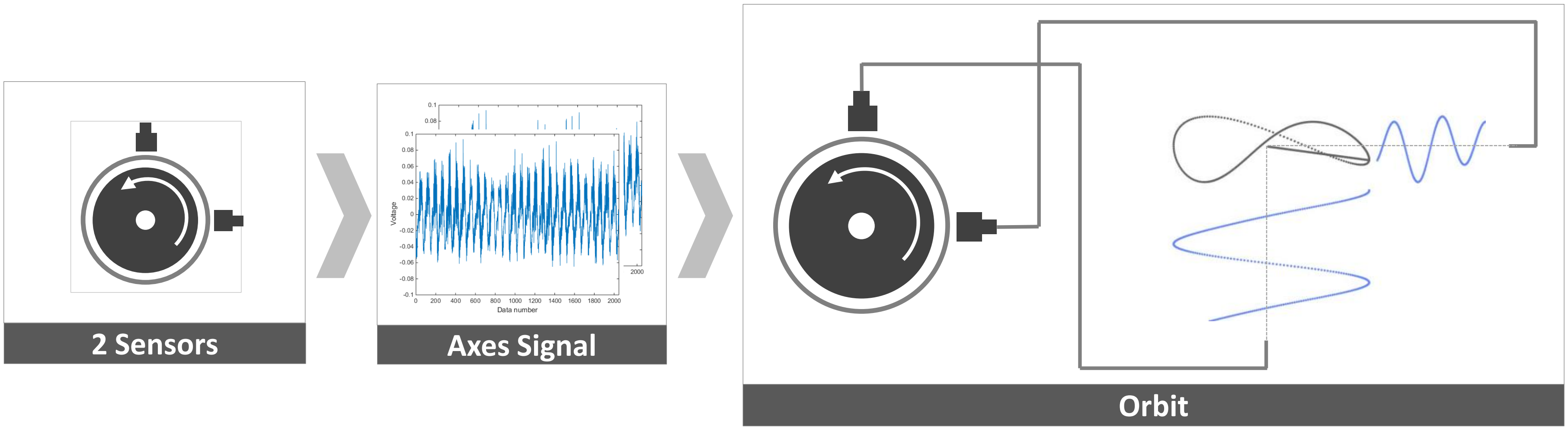
Time-frequency



Orbit Analysis

Orbit Analysis for Rotating Machinery

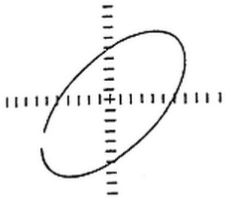
- Visualize shaft movement
  - Vibration information in 2D



- Still manually monitored by human operators in most power plants

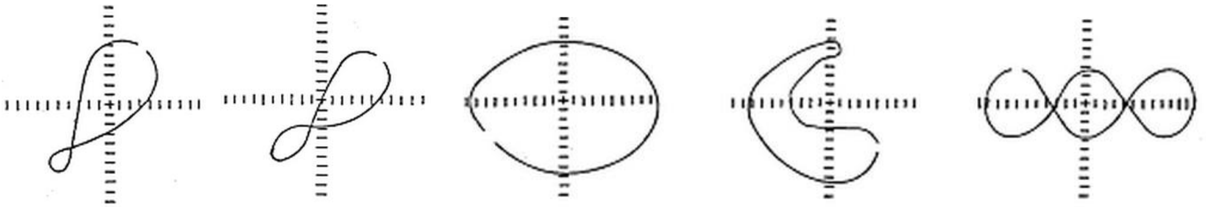
Known-Fault Modes from Orbit Shapes

- Unbalance



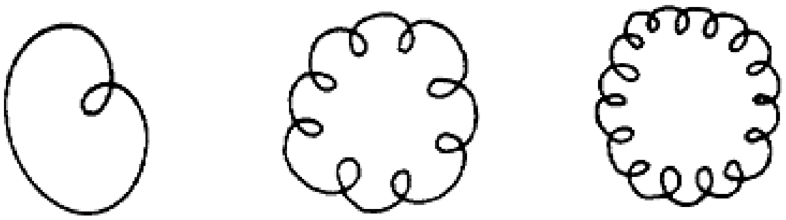
Orbit shape of unbalance

- Misalignment



Orbit shape of misalignment

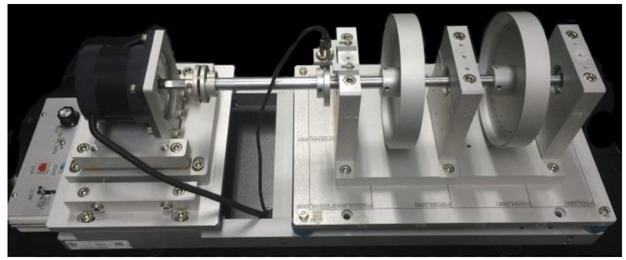
- Hit and rubbing



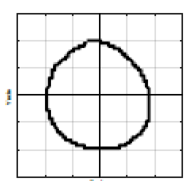
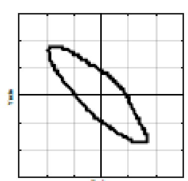
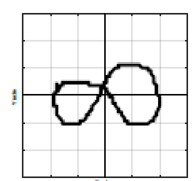
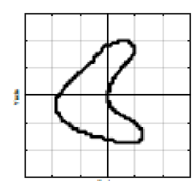
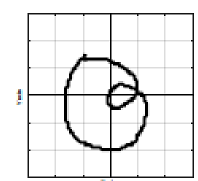
Orbit Shape of hit and bounce rub

Training Data (Data-driven Method)

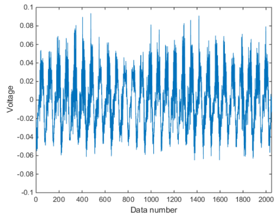
- The orbit vibration data are collected from the rotor kit



- Pre-defined 5 classes of orbit
  - Each shape is related to the specific spindle rotor status
  - 150 orbit images are acquired for each pattern

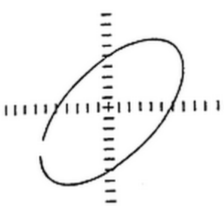
	Normal	Unbalance	Misalignment		Rubbing
Fault	Circle (C)	Ellipse (E)	Eight (8)	Heart (H)	Tornado (T)
Orbit Shape					

Proposed Idea



Orbit Shape → Deep Learning → Fault Detection

- Signal to image

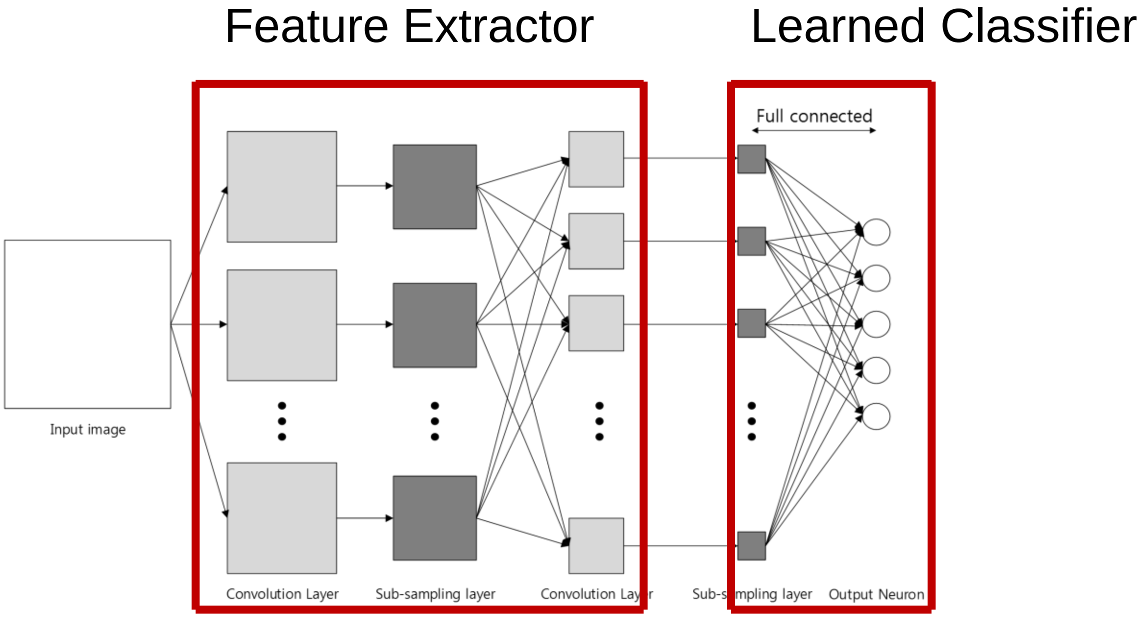


- Image pattern recognition
- Deep learning
  (Google, Facebook, …)

- Use known-fault modes

Deep Learning

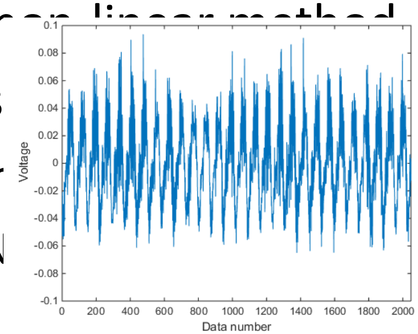
- Neural networks
  - Simple neurons, nonlinear activation functions
- Abstraction from combination of non-linear method
- Automatic discovery of the representation for classification

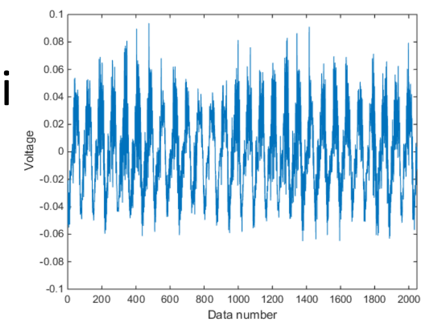


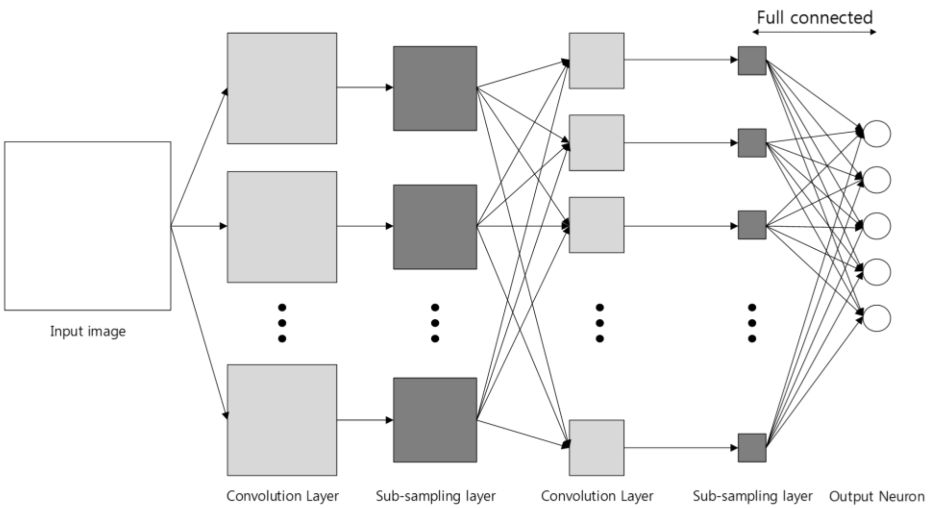
Structure of Convolutional Neural Networks

Deep Learning

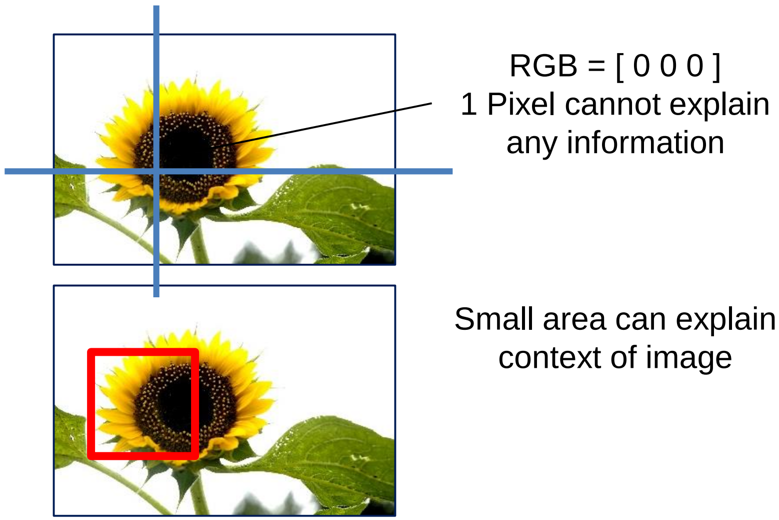
- Neural networks
  - Simple neurons, nonlinear activation functions
- Abstraction from combination of n
- Automatic discovery of the repres cati
- Image pattern recognition probler
  - Convolutional Neural Networks (CN
  - Perception like humans







Structure of Convolutional Neural Networks

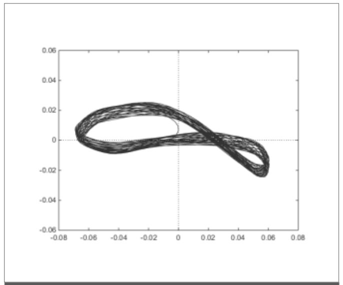


Key idea of Convolutional Neural Networks

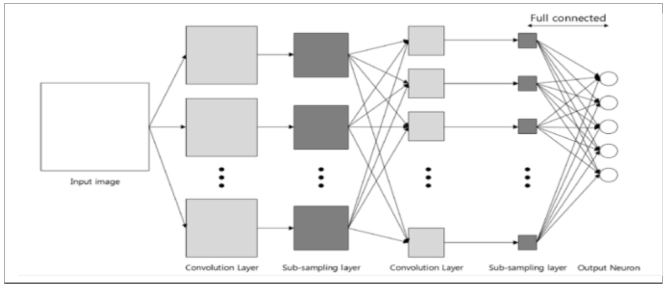
Deep Learning on Orbit Images

- Autonomous orbit image pattern recognition
- Two processes: Training and classification

Training Process



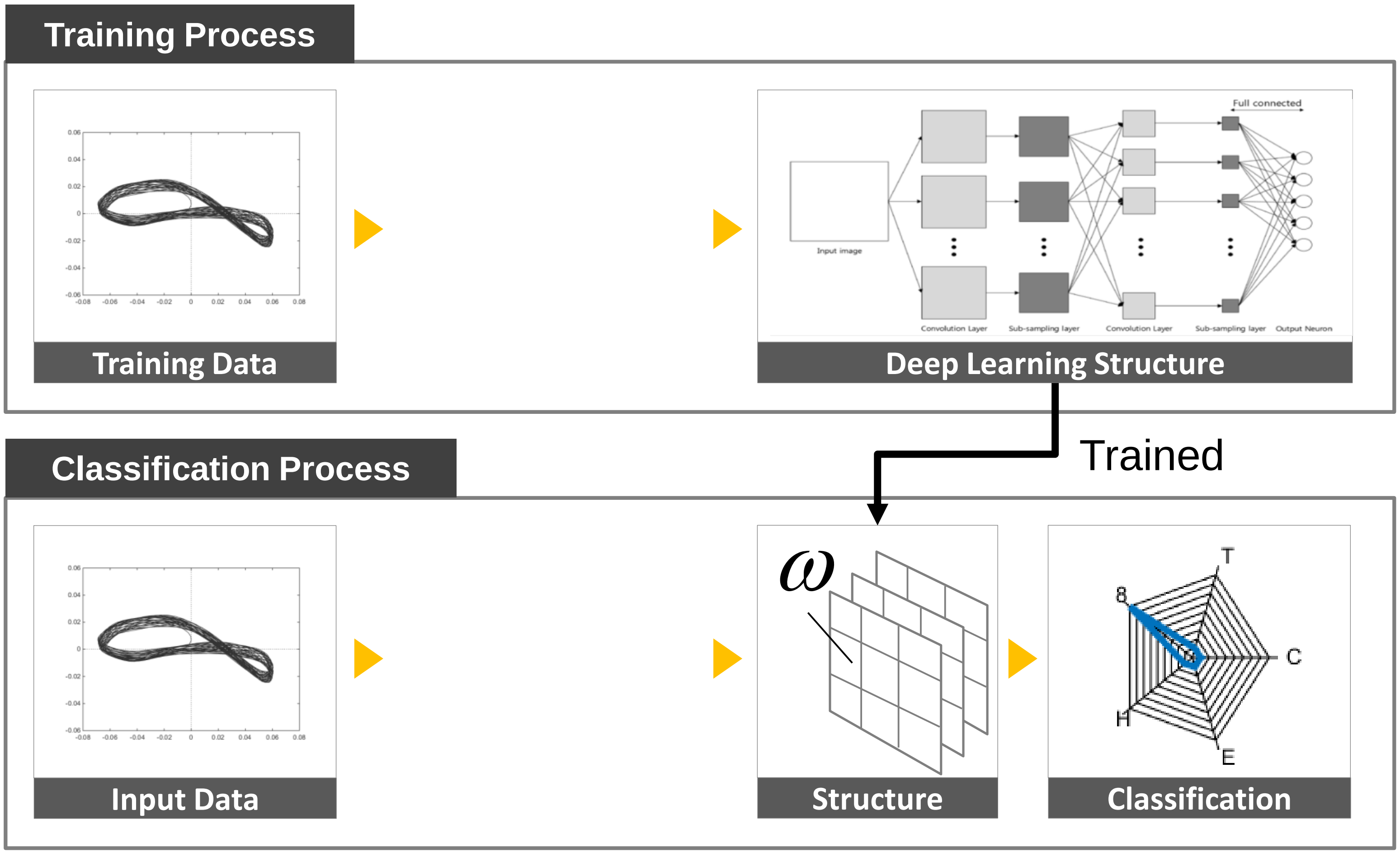
Training Data



Deep Learning Structure

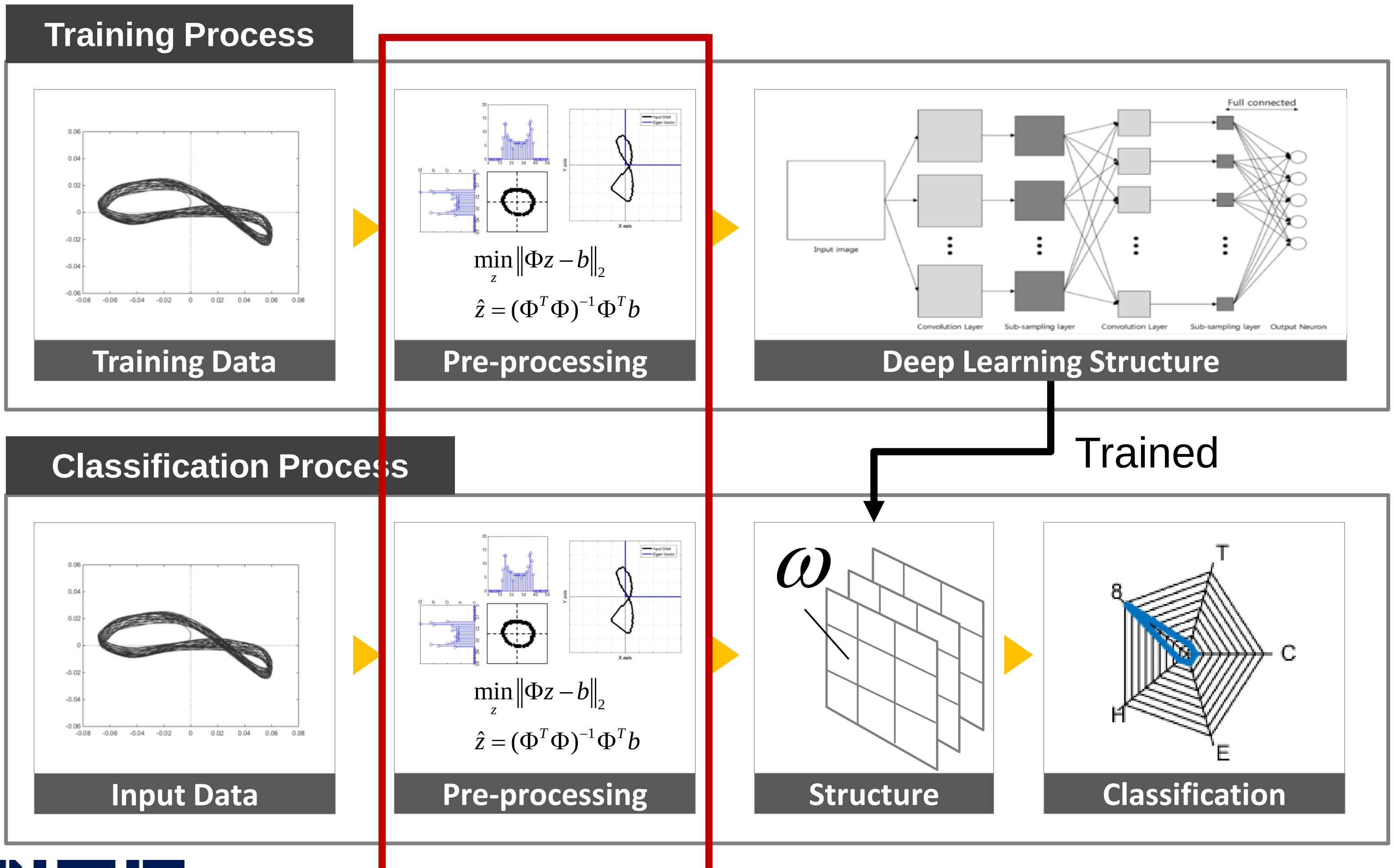
Deep Learning on Orbit Images

- Autonomous orbit image pattern recognition
- Two processes: Training and classification



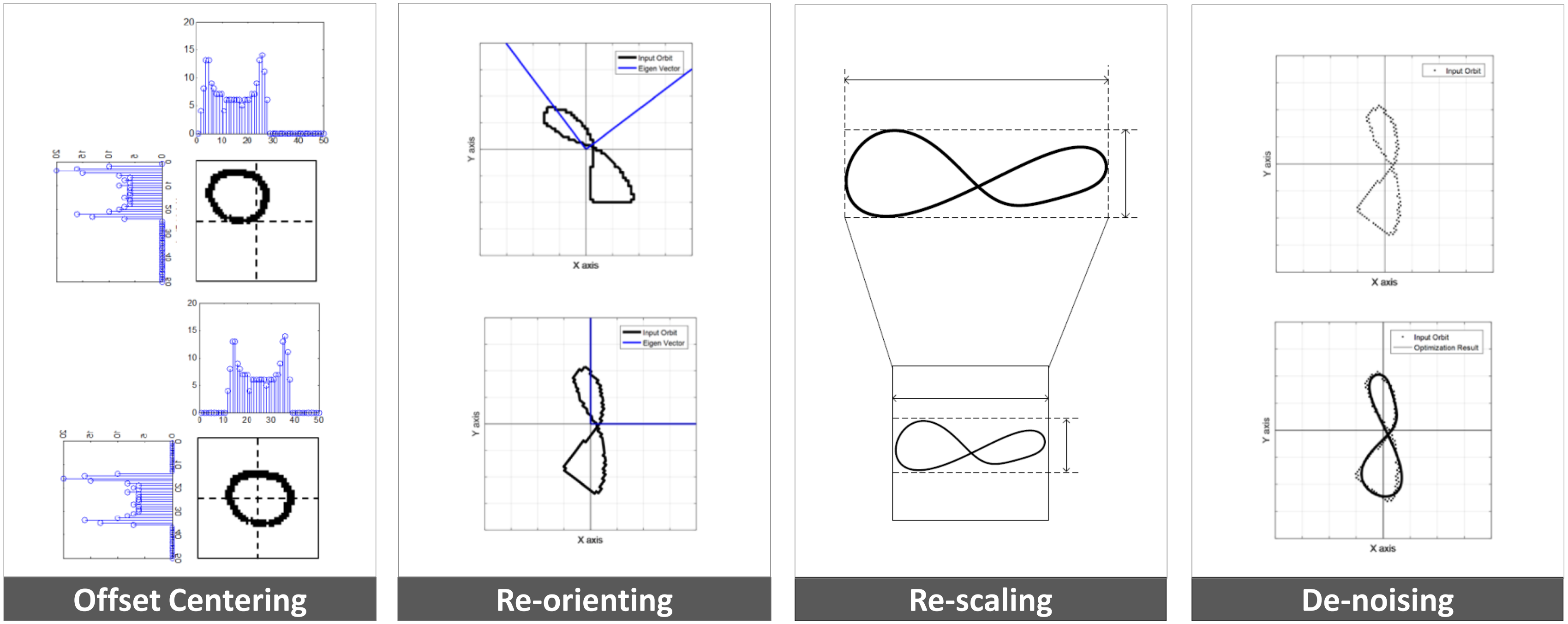
Deep Learning on Orbit Images

- Autonomous orbit image pattern recognition
- Two processes: Training and classification

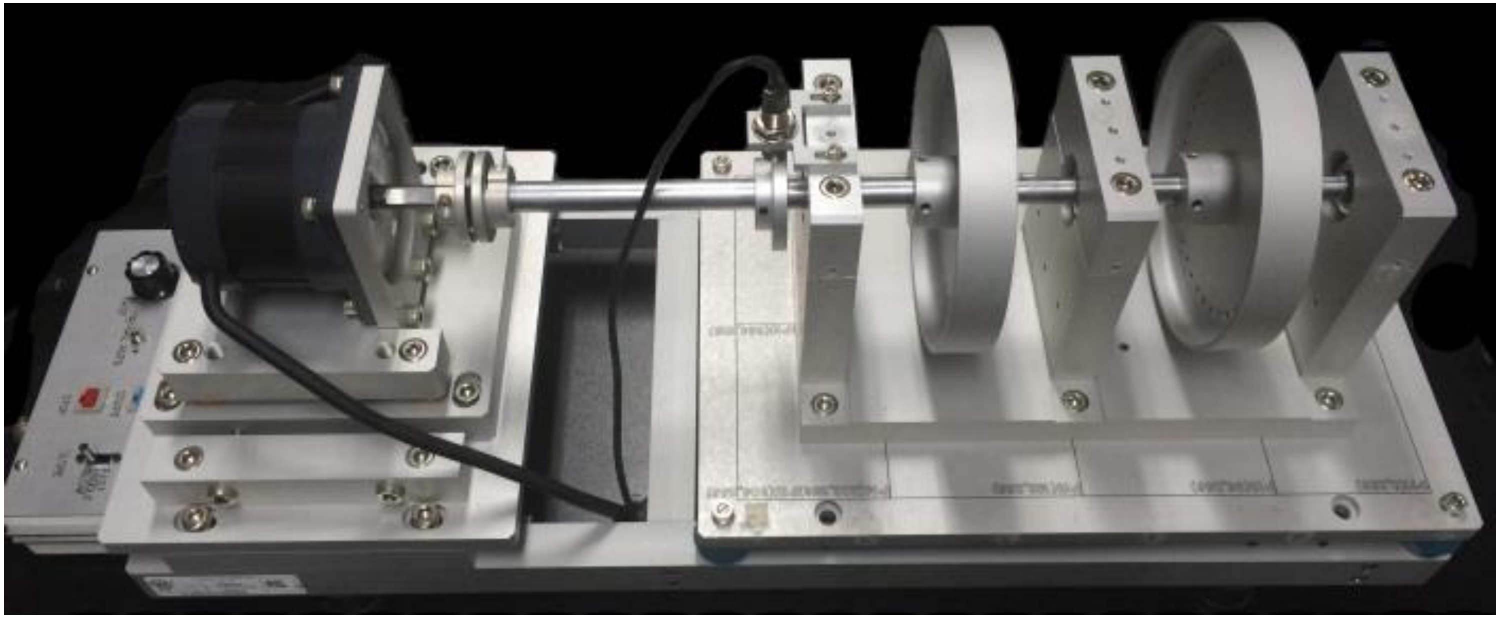


Pre-processing Steps for Better Classification

- Independent of orbit image pattern
  – Location, rotated angle and size
- Maximize performance of training data set
  - Although CNN is kind of capable to handle such local variations

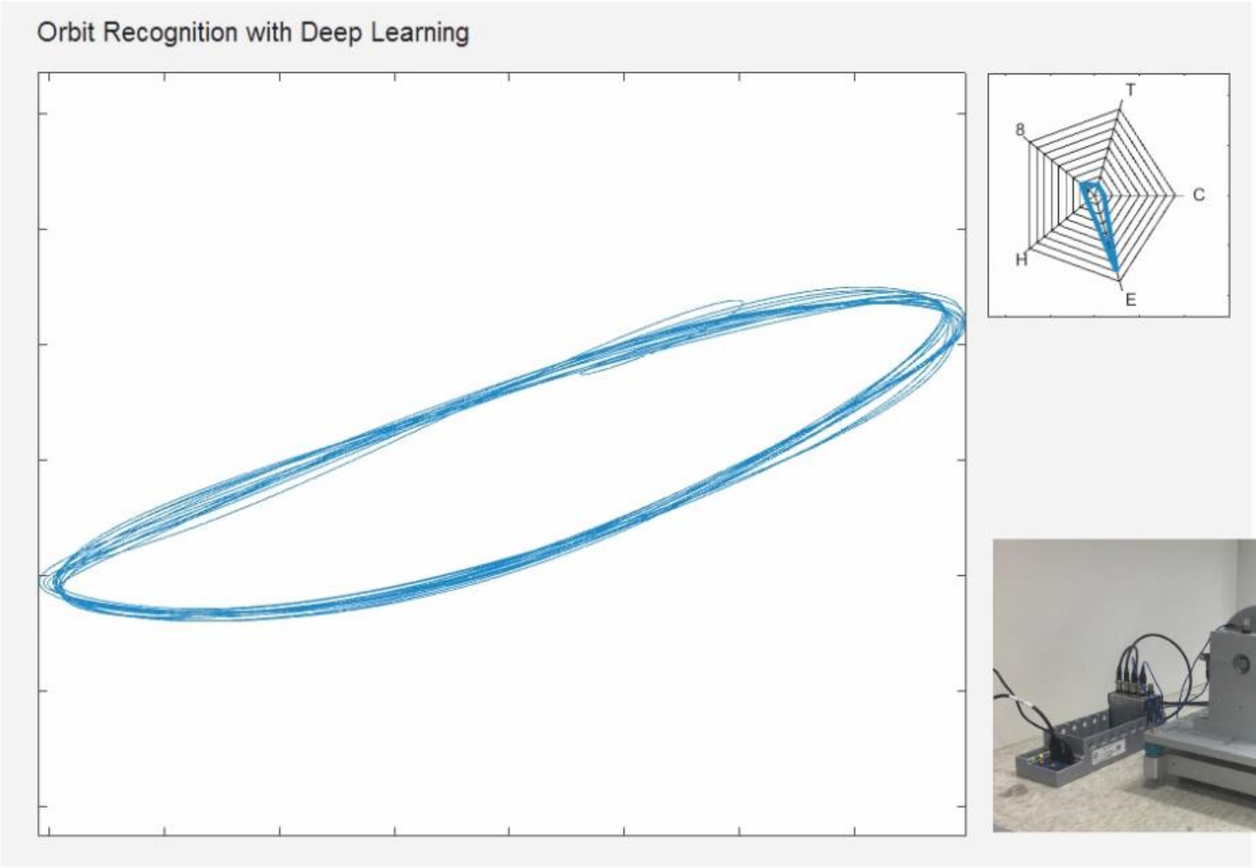


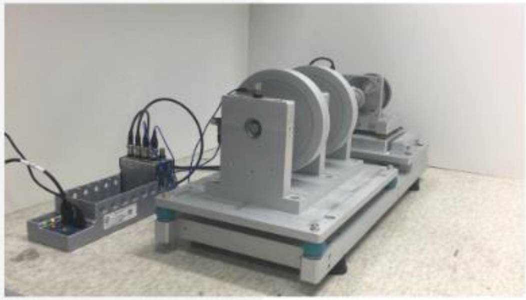
Experiment Results



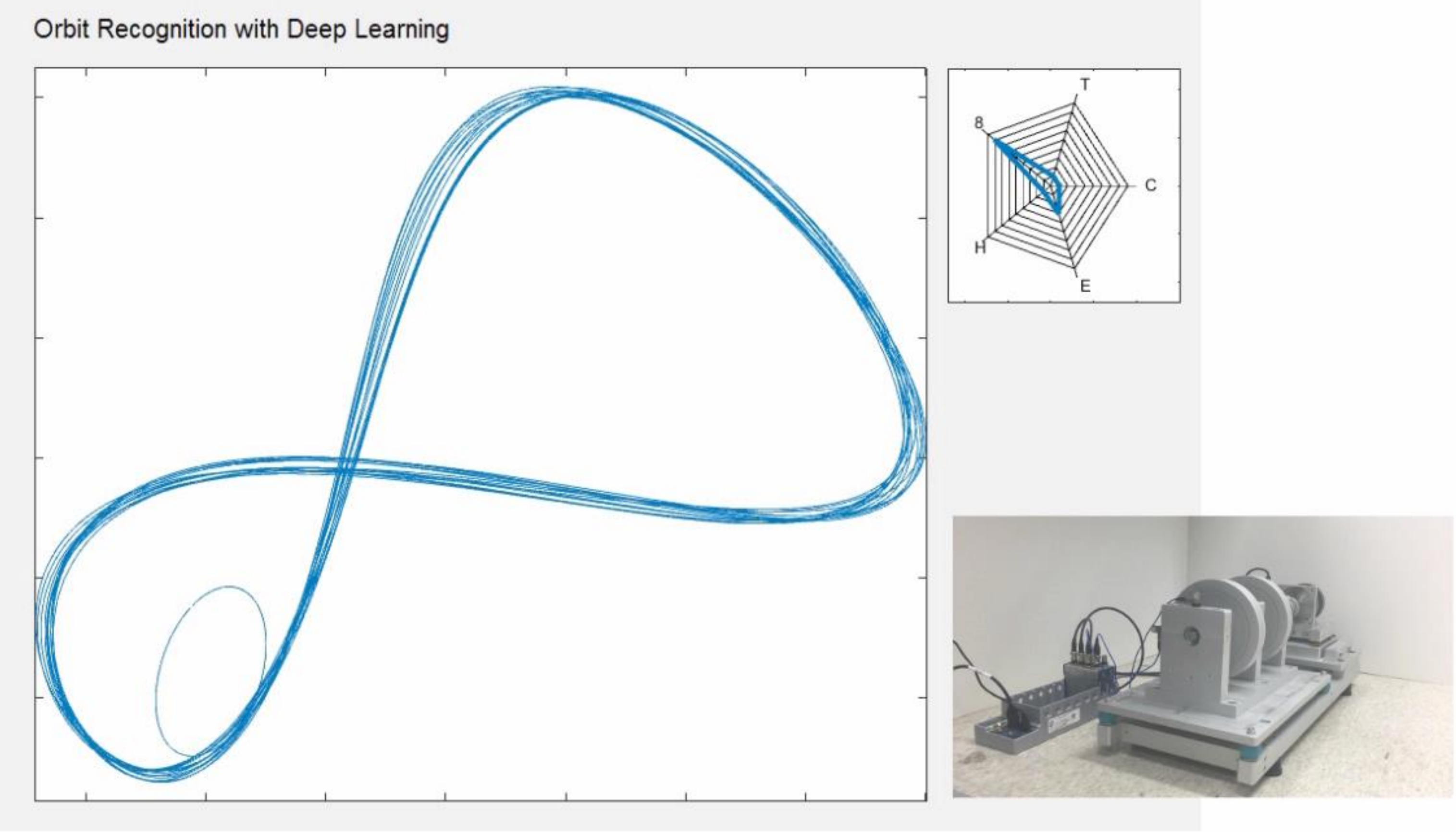
Orbit: Circle

Ellipse

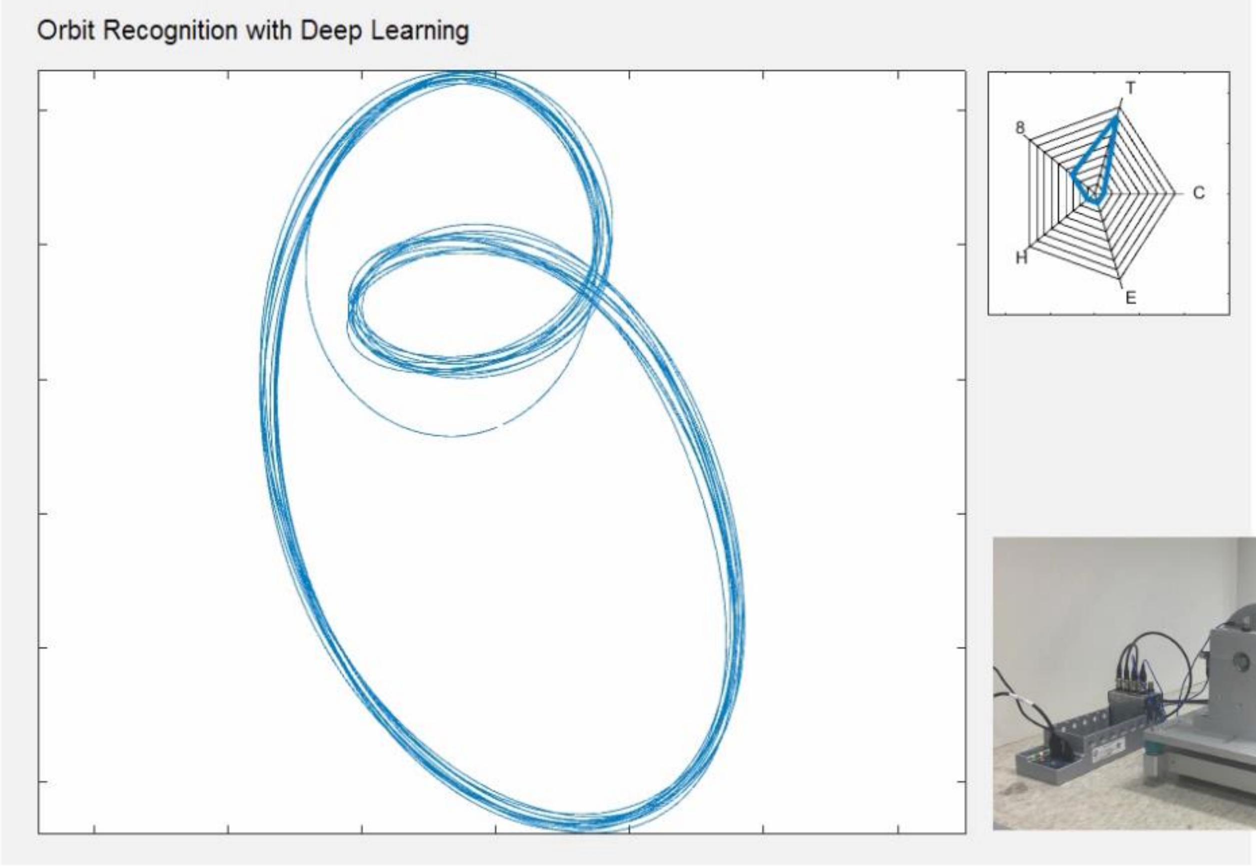




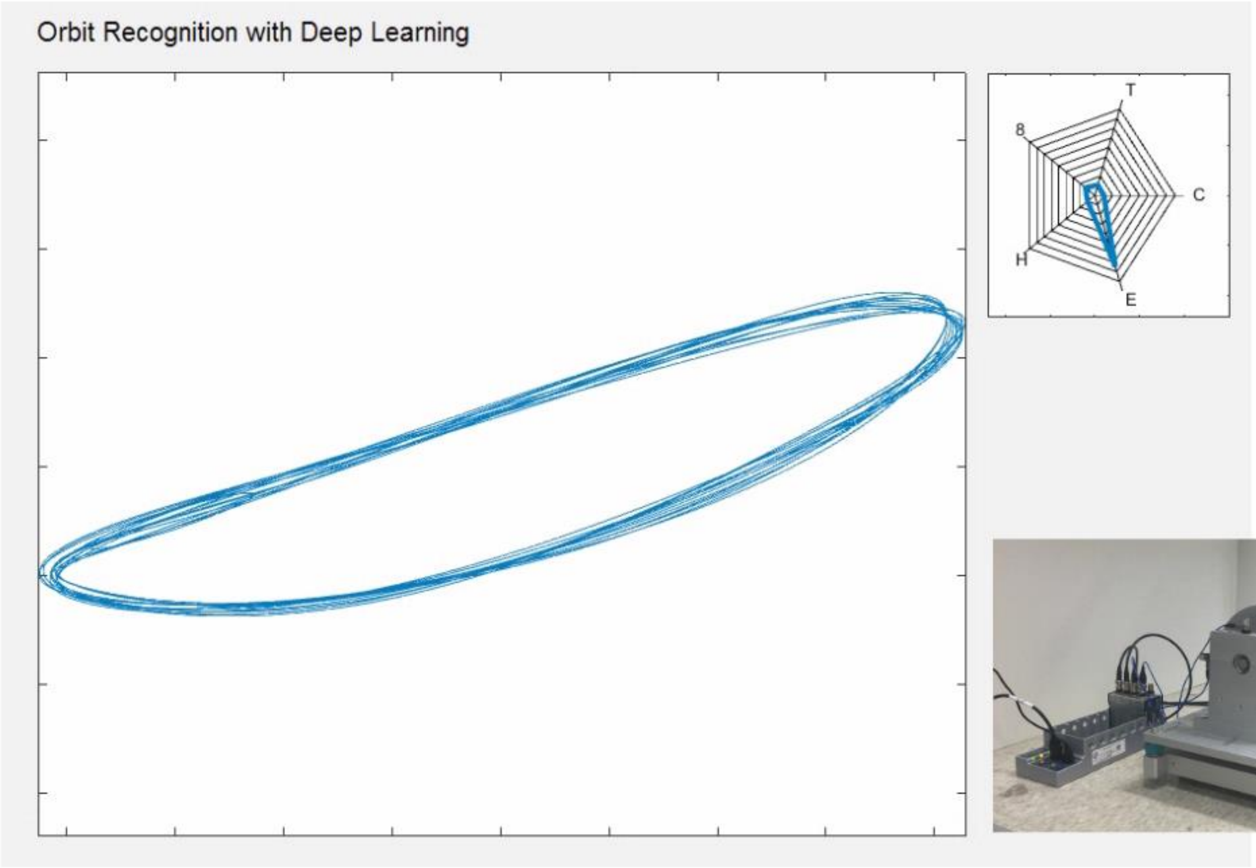
Eight, 8

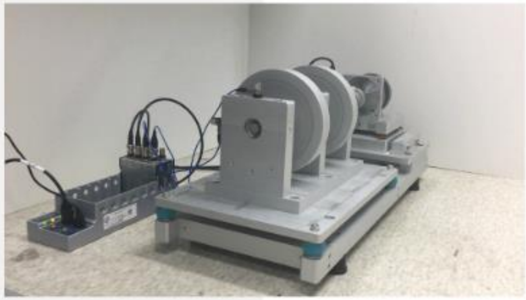


Tornado



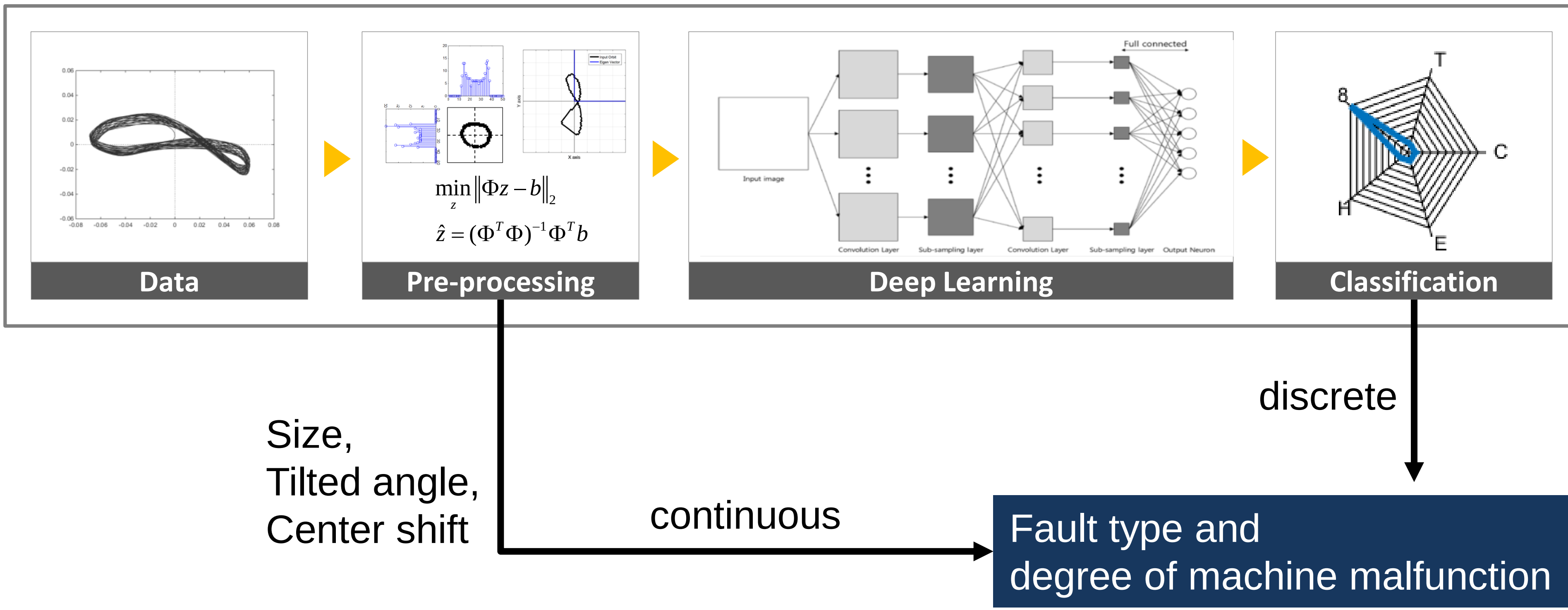
Mode Changes





Advantages

- No need data from fault modes
  - One of challenges of data-driven PHM approach
  - Orbit pattern from rotor dynamics (system-based or model-based)
- Continuous health condition status



Benchmark: Comparison

Method	Feature	Input	Structure	Error
Deep Learning	Auto Extraction	50×50 Image	• Convolutional Neural Networks • 1 Input Layer • 3 Layers ▪ Convolution Layer ▪ Sub-sampling Layer • 1 Output Layer	**1.1%**
Artificial Neural Networks (ANN)	Harmonics forward, backward vector coefficients • Real Value • Imaginary Value	8×1 Vector	• 1 Input Layer ▪ 8 neurons • 1 Hidden Layer ▪ 100 neurons • 1 Output Layer ▪ 5 neurons	8.5%
Gaussian Discriminant Analysis (GDA)		8×1 Vector	• Mean Vector • Covariance Matrix	6.0%

Feature selection/Extraction

Conclusions

- Orbit Image as Features for Machine Diagnosis
- Deep Learning for Better Estimation Accuracy
- Validate with a Testbed

- System-based
  - Known orbit pattern → no need a prior data collection
- Auto feature extraction via deep learning