# MATLAB EXPO 2021

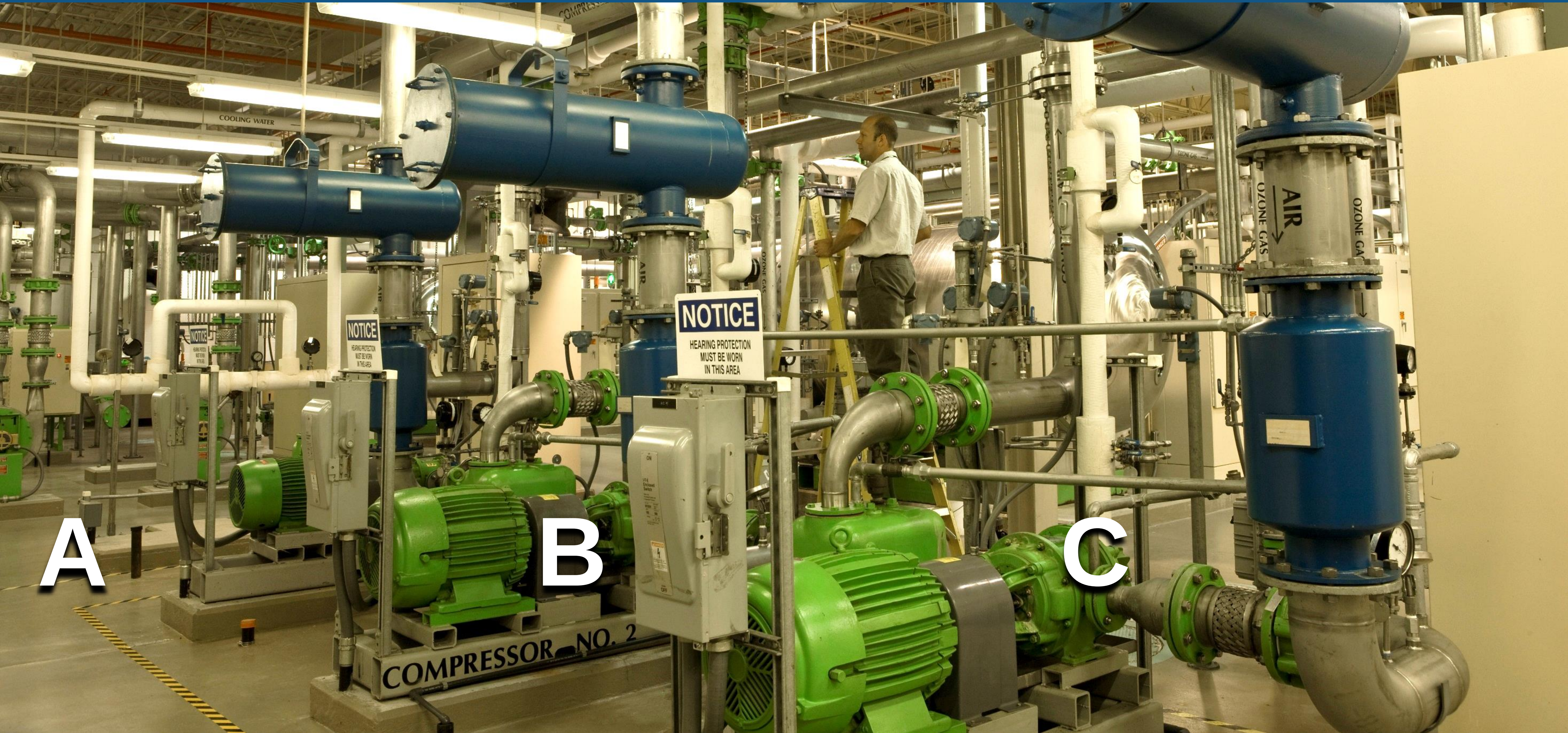
## Predictive Maintenance Using Deep Learning

*Sudheer Nuggehalli*

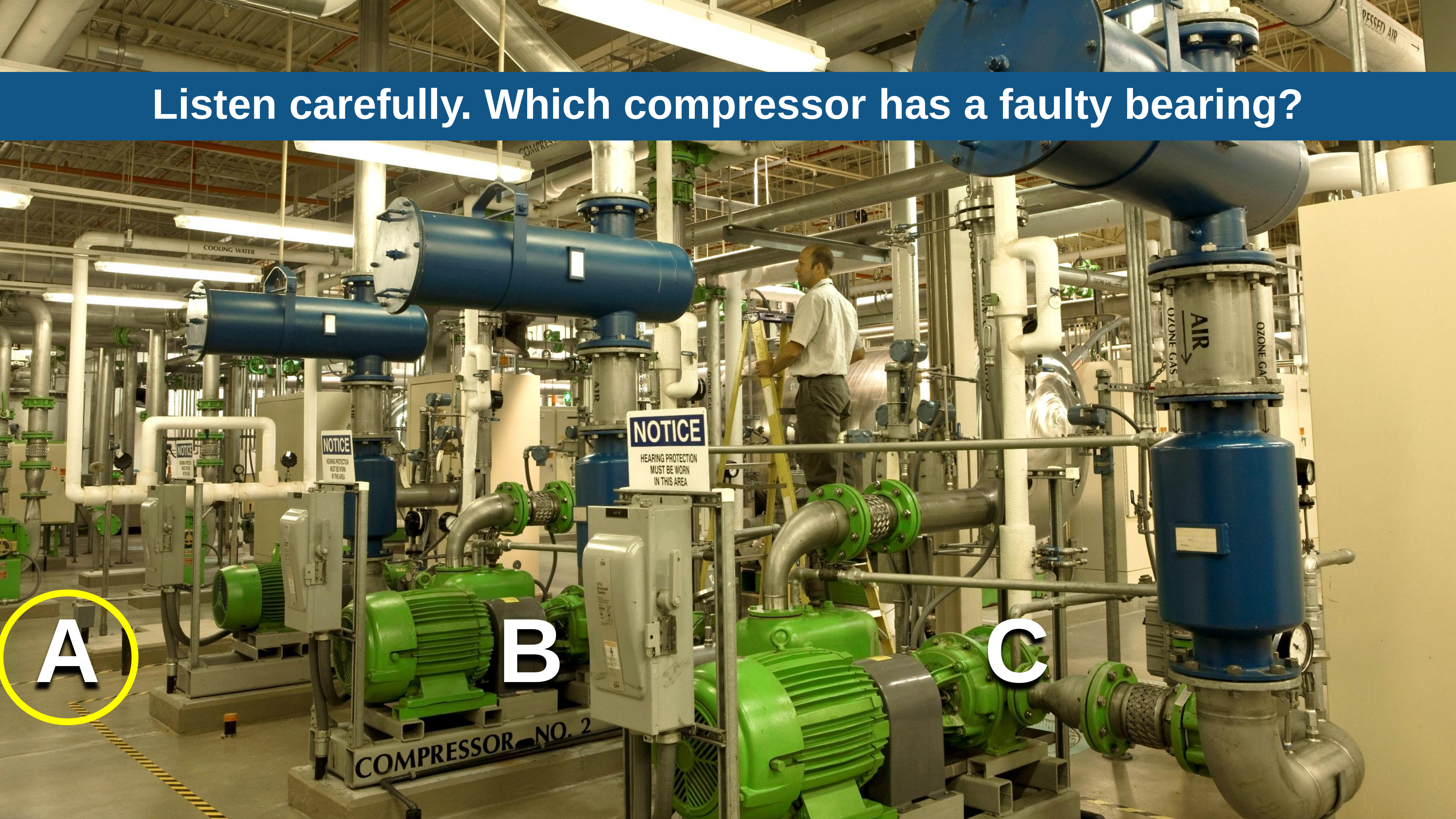
*Rachel Johnson*

MathWorks®

# Listen carefully. Which compressor has a faulty bearing?



# Listen carefully. Which compressor has a faulty bearing?



MATLAB EXPO 2021

# Predictive Maintenance Using Deep Learning

*Sudheer Nuggehalli*

*Rachel Johnson*

MathWorks

# Key Takeaways for Predictive Maintenance

Small gains can yield big rewards.
Try different approaches, including deep learning.

You need AI *and* domain expertise.
MATLAB helps you do both.

MATLAB can automate your entire workflow

## Journey 1:
## *Do you speak air compressor?*

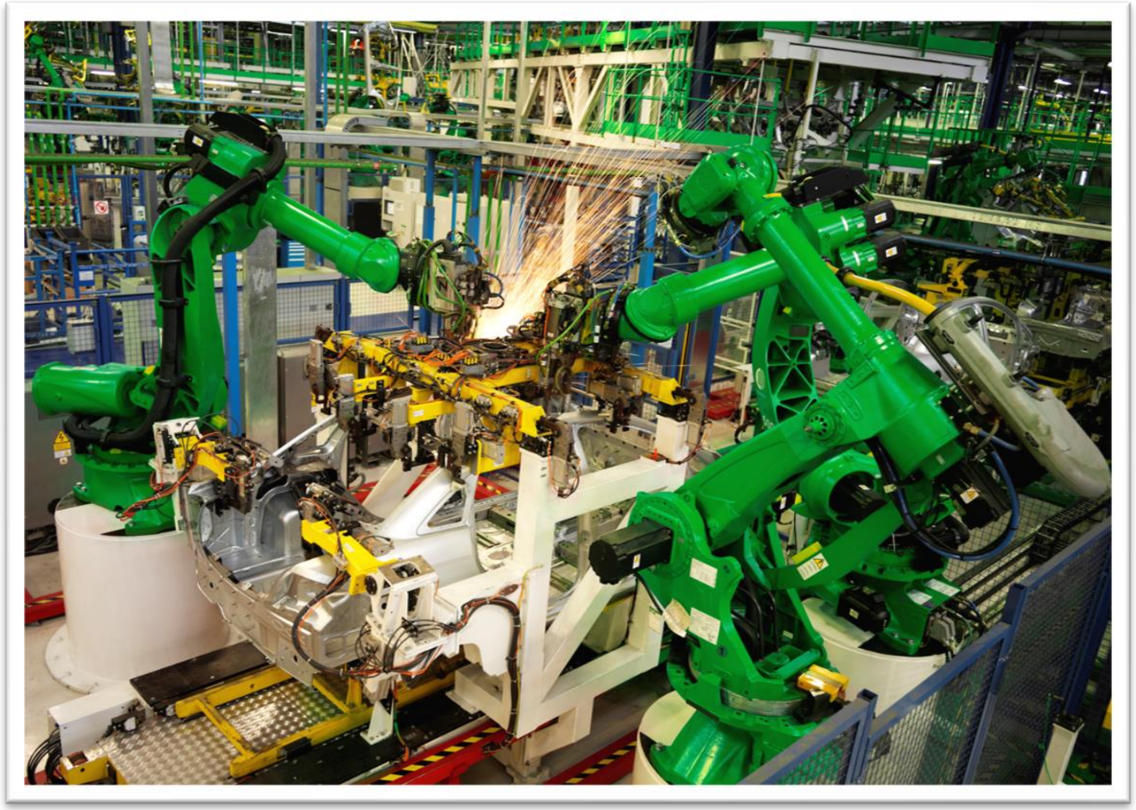

**Fault Isolation with Acoustic Data**

## Journey 2:
## *Data, data, everywhere*

**Anomaly Detection with Vibration Data**

# Meet Rachel*

- Mechanical Engineer at Membrane Manufacturing**
- Responsible for a fleet of industrial machines
- New company AI initiative
- No deep learning experience



Membrane Manufacturing

*Rachel is an actor who works at MathWorks
**Not a real company

# Predictive Maintenance Workflow

## DATA PREPARATION

- Data access and preprocessing
- Simulation-based data generation
- Feature engineering

# Predictive Maintenance Workflow

## DATA PREPARATION

- Data access and preprocessing
- Simulation-based data generation
- Feature engineering

## AI MODELING

- Model design and tuning
- Hardware-accelerated training
- Model exchange across frameworks

# Predictive Maintenance Workflow

## DATA PREPARATION

- Data access and preprocessing
- Simulation-based data generation
- Feature engineering

## AI MODELING

- Model design and tuning
- Hardware-accelerated training
- Model exchange across frameworks

## DEPLOYMENT

- Embedded Devices
- Enterprise Systems
- Edge, cloud, desktop

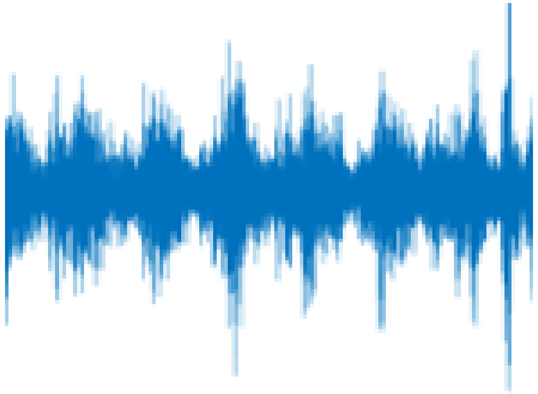
**ITERATION & REFINEMENT**

# **Journey 1:** Do you speak air compressor?

# **Journey 1:** Do you speak air compressor?

**Goal** | Data | Approach | Result

- **Fault detection:** Identify specific faults to enable maintenance staff to respond more quickly

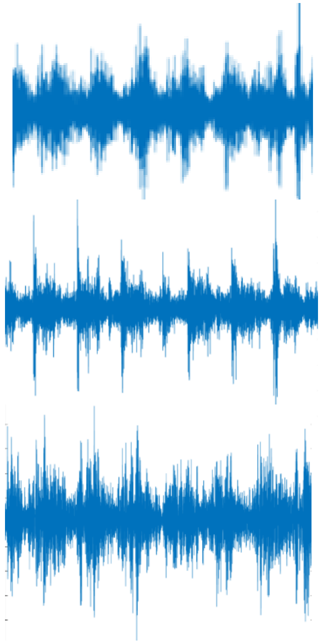



?

# **Journey 1:** Do you speak air compressor?

Goal | **Data** | Approach | Result

- Acoustic time series data from sensors
- Labeled faults from maintenance logs

1. Healthy
2. Leakage Inlet Valve fault
3. Leakage Outlet Valve fault
4. Non-Return Valve fault
5. Piston Ring fault
6. Flywheel fault
7. Rider Belt fault
8. Bearing fault

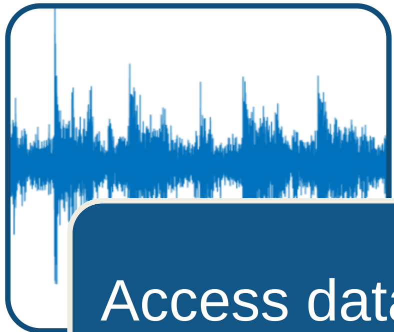
# **Journey 1:** Do you speak air compressor?

Goal | Data | **Approach** | Result

| Method | Validation Accuracy |
|---|---|
| Ensemble Bagged Trees | 88% |
| Deep Neural Network | ? |

# **Journey 1:** Do you speak air compressor?

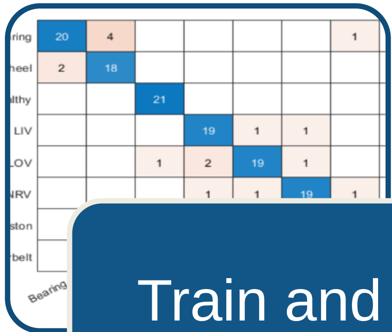
**Goal** | **Data** | **Approach** | **Result**



Access data with datastore

```
audioFeatureExtractor('SampleRate
Window',hamming(windowLength,'perio
OverlapLength',overlapLength,...
spectralCentroid',true, ...
spectralCrest',true, ...
spectralDecrease',true, ...
spectralEntropy',true,...
spectralFlatness',true,...
```

Extract features with Audio Toolbox

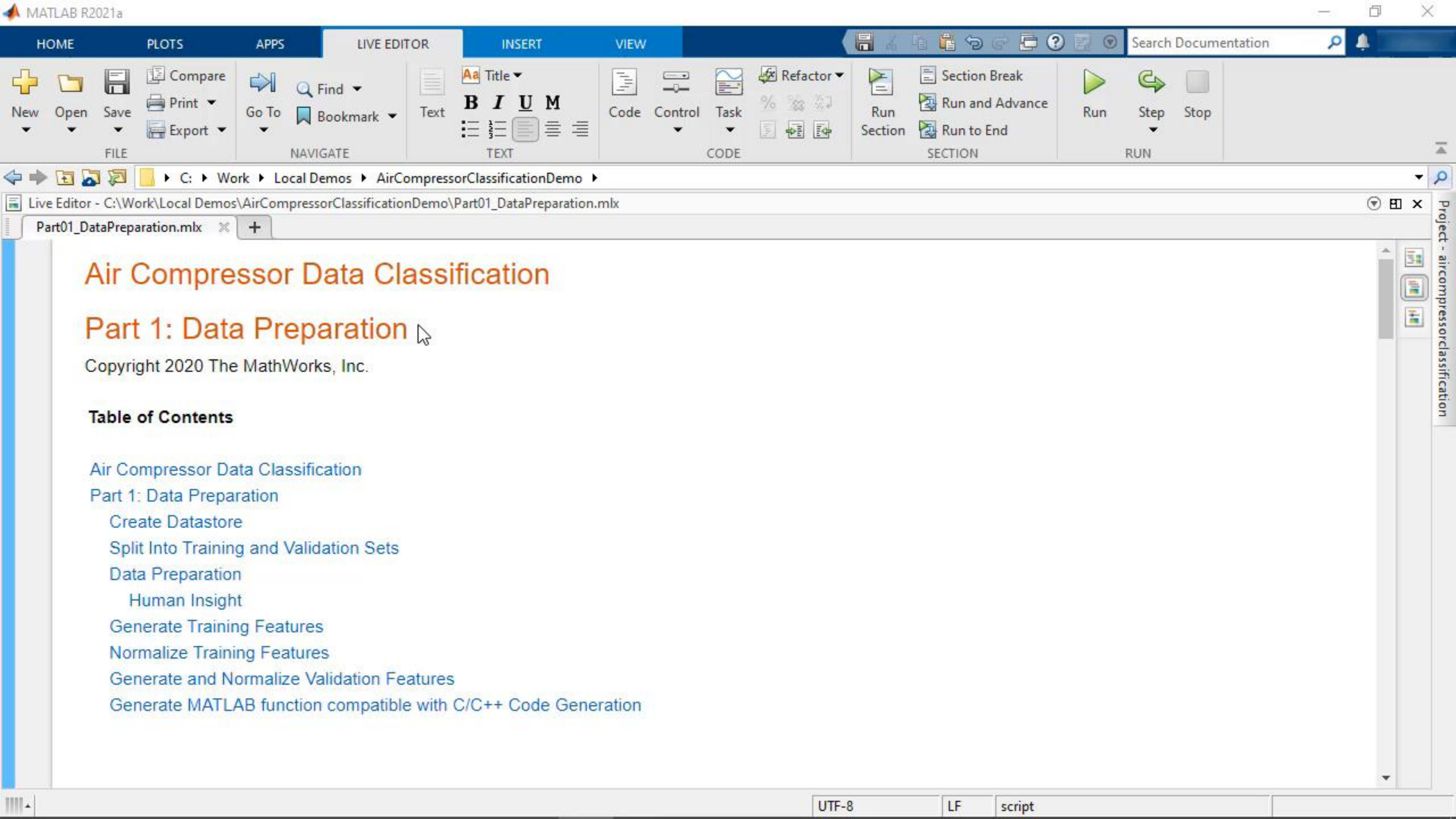


Train and validate LSTM

```
d extractFeatures_init

onfig.linearSpectrum.N
or (int i = 0; i < 257
 config.OneSidedSpectr
+ 1U);
 config.linearSpectrum
```

Generate C code for edge deployment

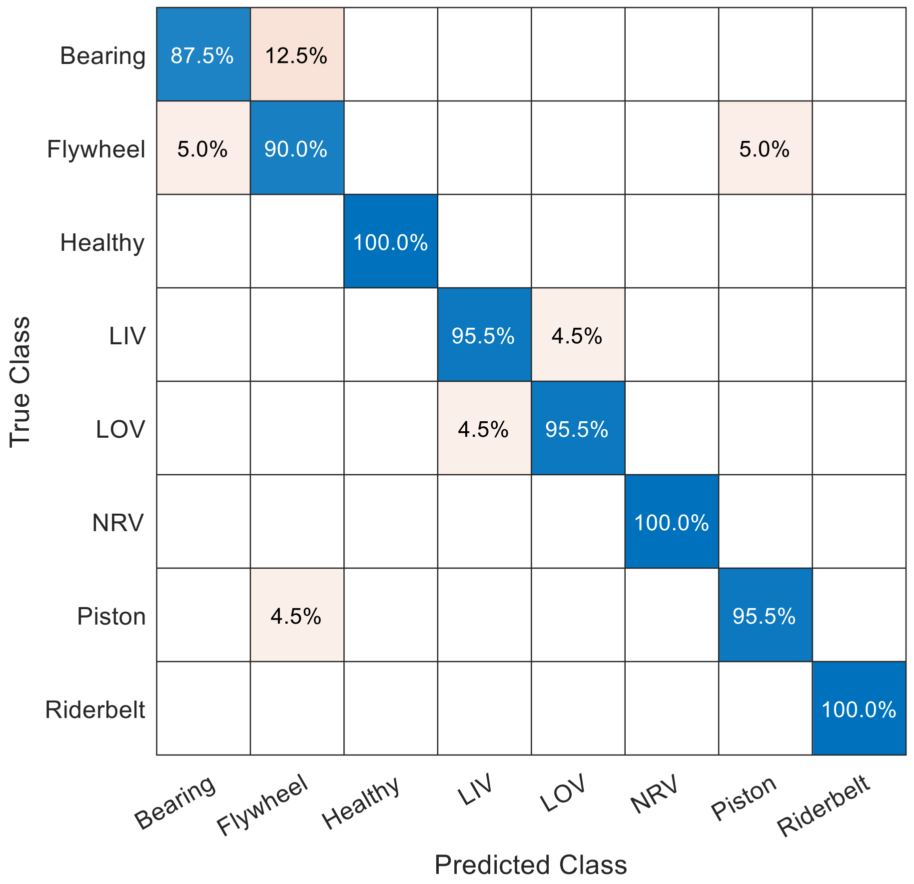

MATLAB R2021a
HOME
PLOTS
APPS
LIVE EDITOR
INSERT
VIEW
Search Documentation
New
Open
Save
Compare
Print
Export
FILE
Go To
Find
Bookmark
NAVIGATE
Text
Title
B
I
U
M
TEXT
Code
Control
Task
Refactor
CODE
Run Section
Section Break
Run and Advance
Run to End
SECTION
Run
Step
Stop
RUN
C:
Work
Local Demos
AirCompressorClassificationDemo
Live Editor - C:\Work\Local Demos\AirCompressorClassificationDemo\Part01_DataPreparation.mlx
Part01_DataPreparation.mlx
Project - aircompressorclassification
Air Compressor Data Classification
Part 1: Data Preparation
Copyright 2020 The MathWorks, Inc.
Table of Contents
Air Compressor Data Classification
Part 1: Data Preparation
Create Datastore
Split Into Training and Validation Sets
Data Preparation
Human Insight
Generate Training Features
Normalize Training Features
Generate and Normalize Validation Features
Generate MATLAB function compatible with C/C++ Code Generation
UTF-8
LF
script

# **Journey 1:** Do you speak air compressor?

**Goal** | **Data** | **Approach** | **Result**

- Successfully identified faults with 95% validation accuracy

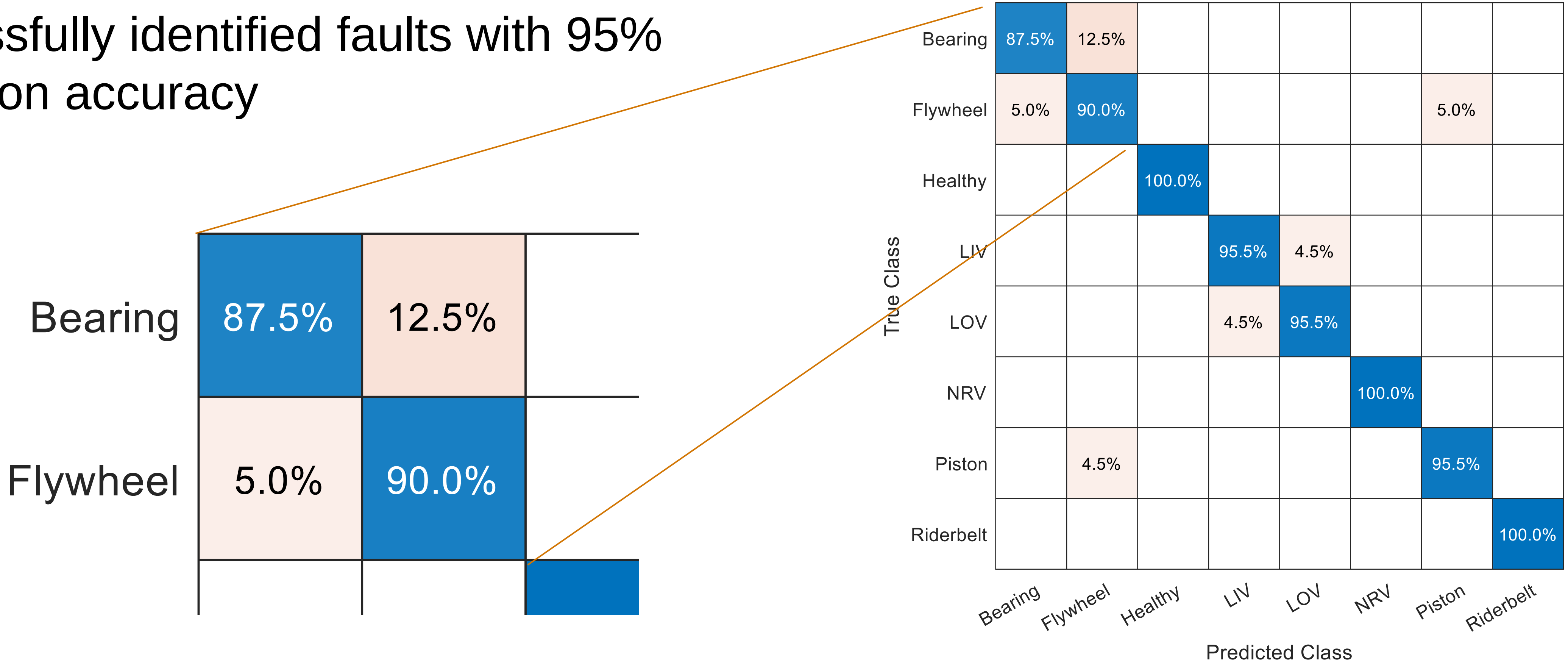
| Method | Validation Accuracy |
| --- | --- |
| Ensemble Bagged Trees | 88% |
| Deep Neural Network | 95% |



# **Journey 1:** Do you speak air compressor?

**Goal** | **Data** | **Approach** | **Result**

- Successfully identified faults with 95% validation accuracy



# **Journey 1:** Do you speak air compressor?

**Goal** | **Data** | **Approach** | **Result**

## **Poll:** How could we improve the results?

- ❑ Collect more data
- ❑ Tune network hyperparameters
- ❑ Try a different feature set
- ❑ Try a different algorithm
- ❑ Buy more GPUs

# **Journey 1:** Do you speak air compressor?

Goal | Data | Approach | **Result**

## **Poll:** How could we improve the results?

- [x] Collect more data
- [x] Tune network hyperparameters
- [x] Try a different feature set
- [x] Try a different algorithm
- [ ] Buy more GPUs

# **Journey 1:** Do you speak air compressor?

## DATA PREPARATION

- Data access and preprocessing
- Simulation-based data generation
- Feature engineering

## AI MODELING

- Model design and tuning
- Hardware-accelerated training
- Model exchange across frameworks

## DEPLOYMENT

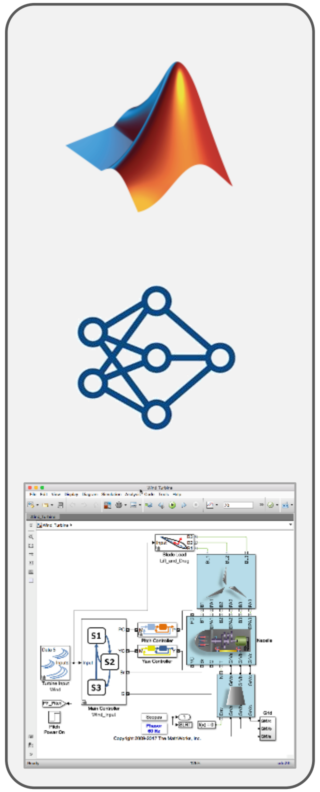
- Embedded Devices
- Enterprise Systems
- Edge, cloud, desktop

**ITERATION & REFINEMENT**

# **Journey 1:** Do you speak air compressor?

## DEPLOYMENT

- Embedded Devices
- Enterprise Systems
- Edge, cloud, desktop



Code Generation

CPU

GPU

FPGA

# **Journey 1:** Do you speak air compressor?

Goal | Data | Approach | **Result**

- What's Next?

MATLAB EXPO

## Deploying AI to Embedded and Production Systems

# **Journey 2:** Data, data, everywhere…

# **Journey 2:** Data, data, everywhere…

**Goal** | Data | Approach | Result

- **Anomaly Detection:** Detect when the machine deviates from normal operation.
- Avoid surprises. Address anomalies before catastrophic failure occurs.

**Currently**

- Routine monthly maintenance
- Not many failures
- But when failures do happen…

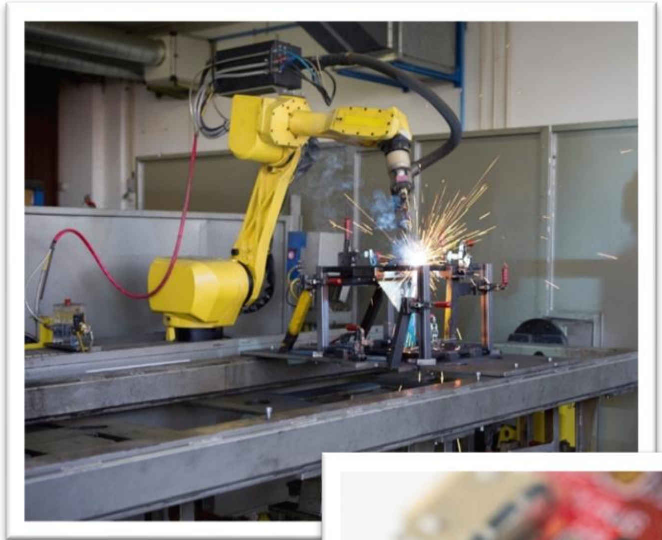
# **Journey 2:** Data, data, everywhere…

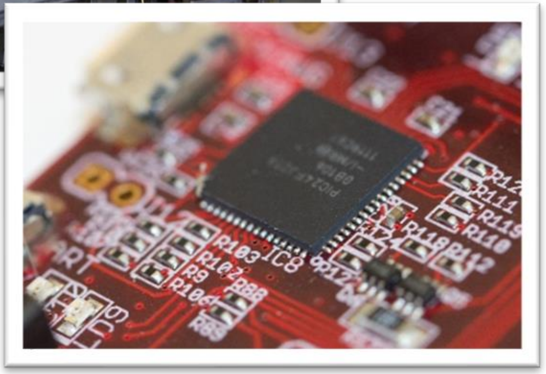
Goal | **Data** | Approach | Result

- Vibration data from 3-axis accelerometers

- Labeled “before” and “after” maintenance
  - “After” data = Normal ✓
  - “Before” data = Not sure **?**

- Some data tagged as “abnormal” by maintenance crews





# Journey 2: Data, data, everywhere…

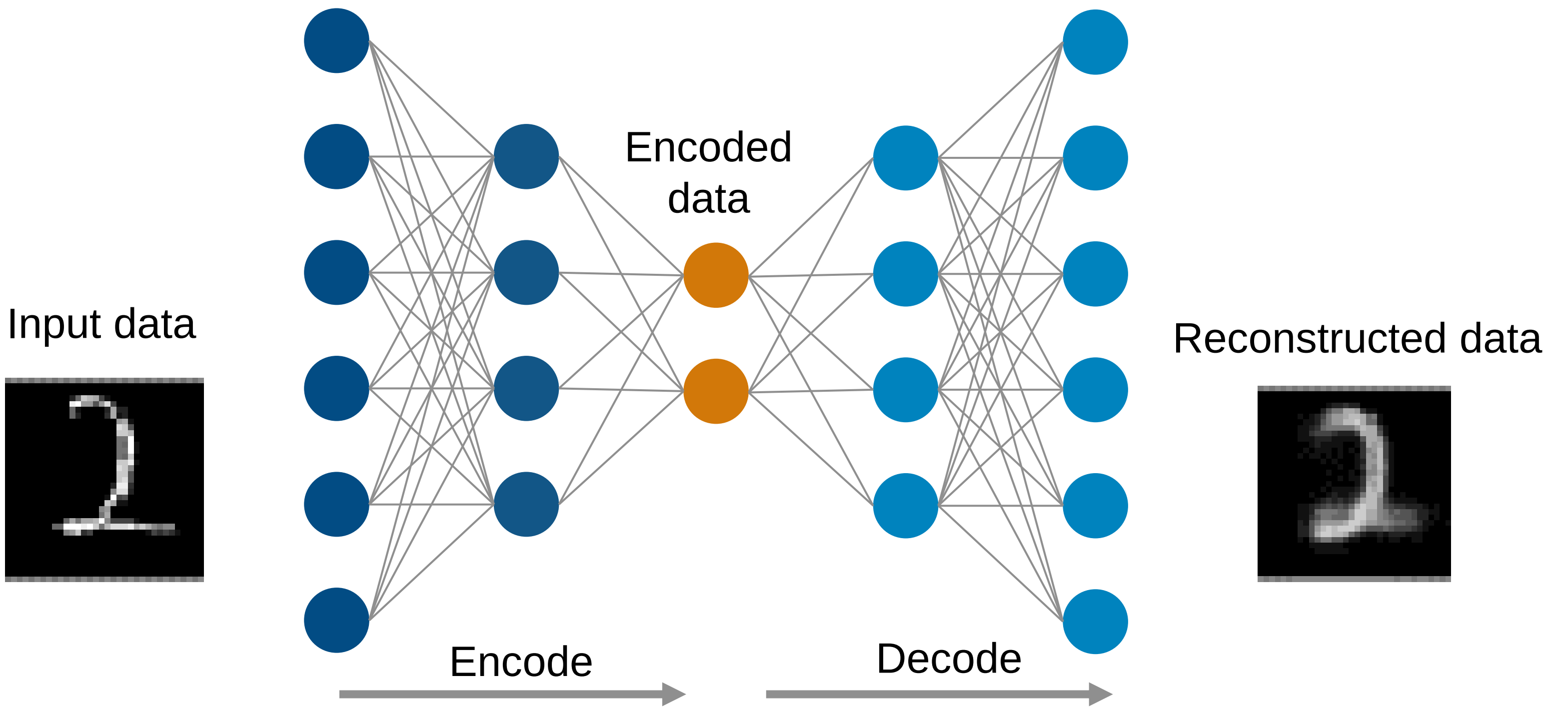
Goal | Data | **Approach** | Result

| Method | Validation Accuracy |
|---|---|
| K-Means Clustering | 85% |
| Autoencoder | ? |

# **Journey 2:** Data, data, everywhere…

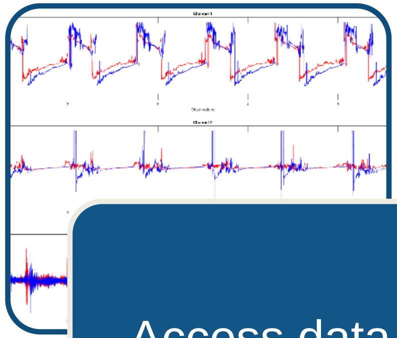
**Goal** | **Data** | **Approach** | **Result**

## Autoencoder



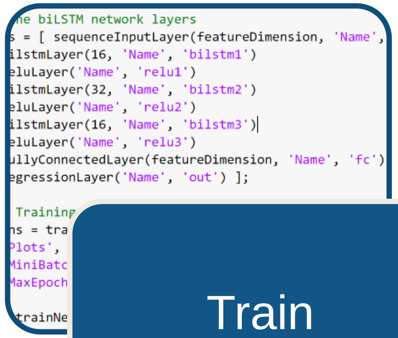
# **Journey 2:** Data, data, everywhere…

**Goal** | **Data** | **Approach** | **Result**

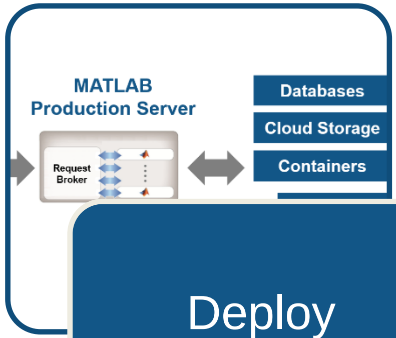


Access data from files

Extract and rank features with Diagnostic Feature Designer App




Train autoencoder on normal data




Deploy algorithms to the cloud

MATLAB R2021a

HOME PLOTS APPS LIVE EDITOR INSERT VIEW

Search Documentation

New Open Save Compare Print Export FILE Go To Find Bookmark NAVIGATE Text Title TEXT Code Control Task Refactor CODE Run Section Section Break Run and Advance Run to End SECTION Run Step Stop RUN

C: ▸ Work ▸ Local Demos ▸ anomaly-detection-using-autoencoders ▸

Live Editor - C:\Work\Local Demos\anomaly-detection-using-autoencoders\Part01_DataPrepFeatureExtraction.mlx

Part01_DataPrepFeatureExtraction.mlx

# Part 1: Data Preparation and Feature Extraction

***Industrial Machinery Anomaly Detection***

**Table of Contents**



## Load Data

```
load("IndustrialMachineData.mat")
```

## Visualize Data Before and After Maintenance

Visualize data before and after maintenance across channels for one member of the ensemble

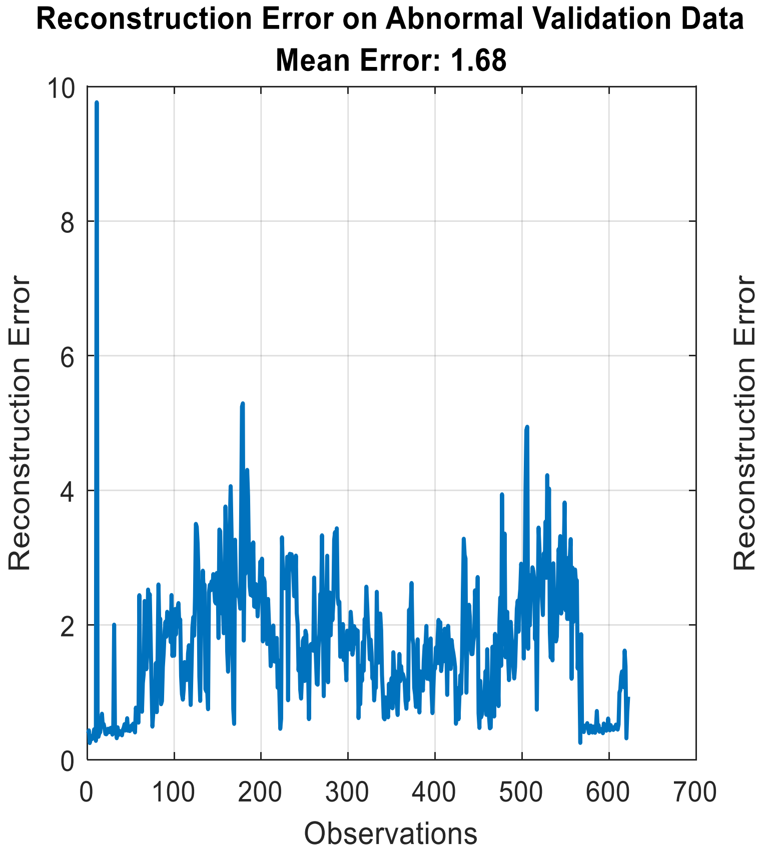
Project - Anomaly Detection Industrial Machine

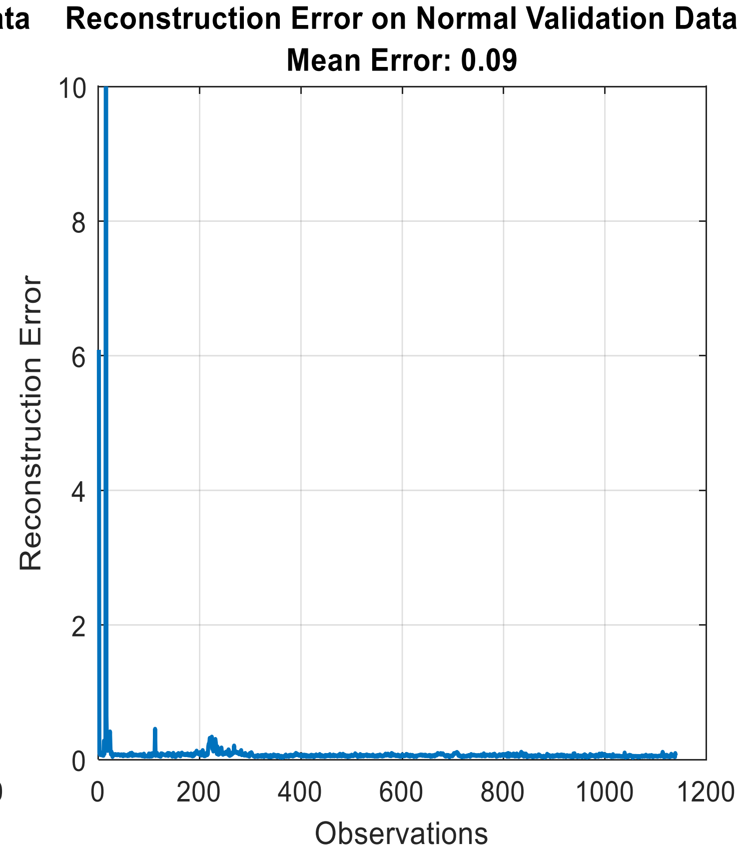
UTF-8 LF script

# **Journey 2:** Data, data, everywhere…

Goal | Data | Approach | **Result**

| Method | Validation Accuracy |
|---|---|
| K-Means Clustering | 85% |
| Autoencoder | 99% |



# **Journey 2:** Data, data, everywhere…

**Goal** | **Data** | **Approach** | **Result**

- What's Next?

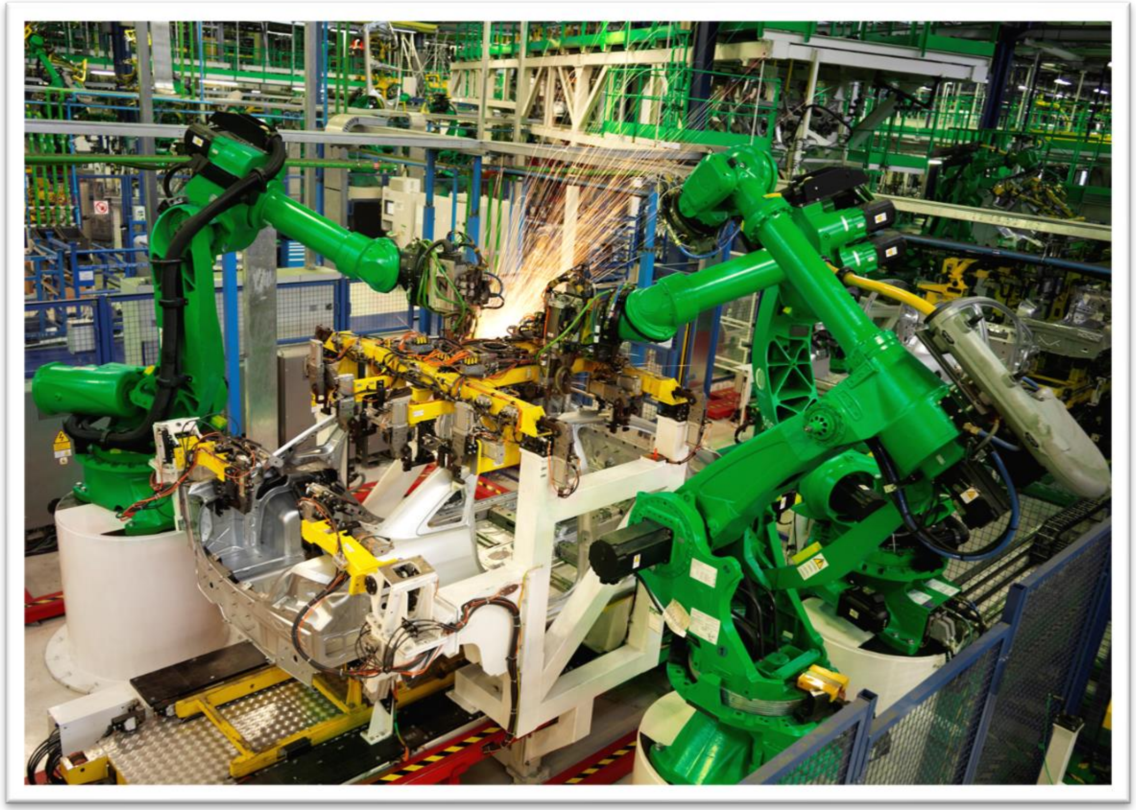
MATLAB EXPO

## DevOps for Software and Systems:
## Putting Algorithms and Models in Operation

Six months later…

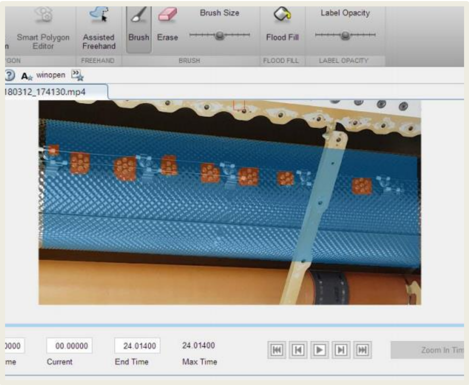
# Six Months Later

- Increased uptime by 10%
- Want to expand to entire fleet, multiple locations
- Next project: Predict Remaining Useful Life (RUL)
- Got a promotion! ☺

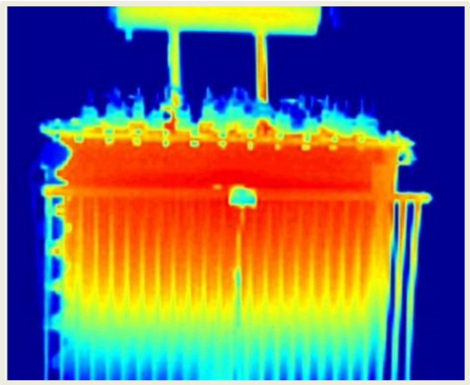


Membrane Manufacturing

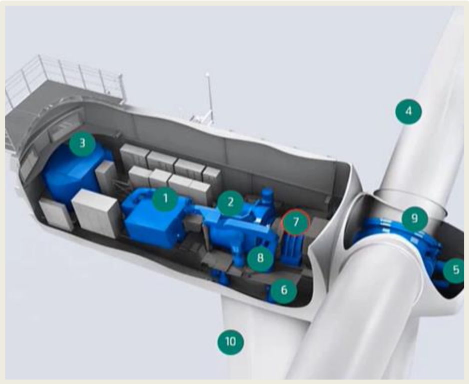
# Companies are succeeding with MATLAB for Predictive Maintenance



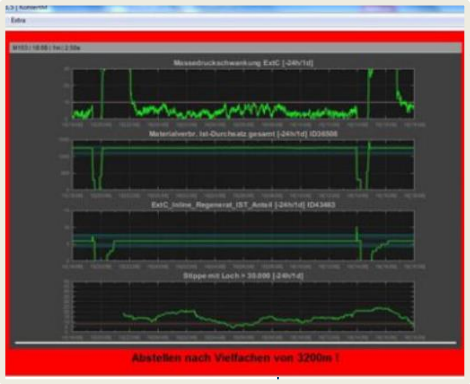

Airbus detects defects in aircraft pipes with semantic segmentation



Siemens develops health monitoring system for distribution transformers



RWE Renewables detects anomalies in wind turbine bearings using neural networks



Mondi develops and deploys algorithms to predict plastic production machine failures

# LG Energy Solution used Deep Learning for Predictive Maintenance on industrial cutter

## Challenge

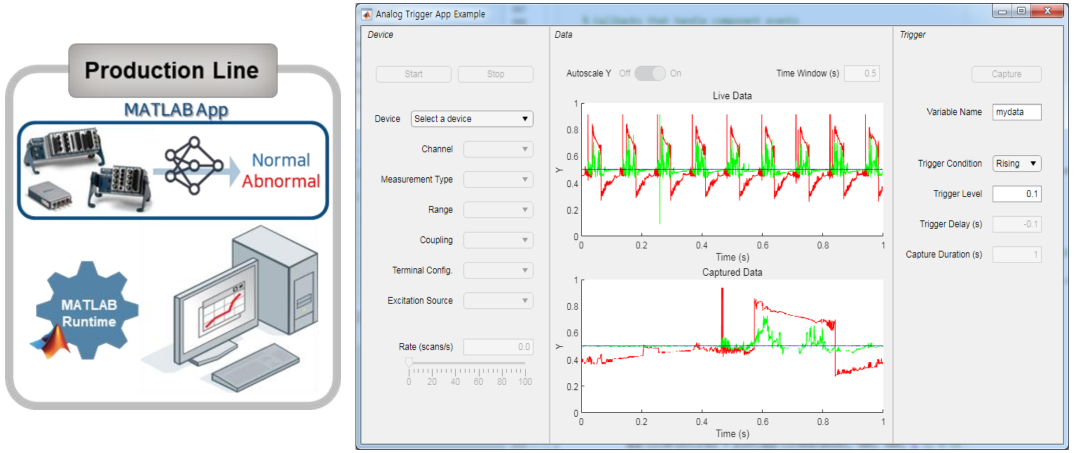
Maintenance of equipment in the factory also depends on the site engineer’s opinion, and sometimes those are a bit conservative

## Solution

Developed a condition monitoring system and deployed standalone executable which can acquire raw data from NI device directly, make a prediction and display the result in GUI

## Advantages of using MATLAB and Simulink

- Interactive Apps for generating features and training various AI models
- Capabilities of entire workflow from data acquisition to deployment
- Leveraged MathWorks engineer’s support for fast prototyping




**Condition monitoring system using Deep Learning**

> *“3 advantages of MATLAB that lead our project to success: App-based AI development workflow, compatibility with 3rd party hardware and short test cycle with rapid prototyping.”*
>
> *Junghoon Lee,* ***LG Energy Solution***

>> [MATLAB for deep learning]

# Key Takeaways for Predictive Maintenance

Small gains can yield big rewards.
Try different approaches, including deep learning.

You need AI *and* domain expertise.
MATLAB helps you do both.

MATLAB can automate your entire
Predictive Maintenance workflow

MATLAB EXPO
2021

# Thank you

MathWorks®