Diagnostics and Prognostics with MATLAB

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Agenda

- Introduction to Prognostics and Diagnostics
- Introduction to Machine Learning
- Demo: Using machine learning to predict failures
- Demo: Deploying a machine learning pipeline to an embedded device
Terminology - Types of Maintenance

- **Reactive** – Do maintenance once there’s a problem
  - Example: replace car battery when it has a problem
  - Problem: unexpected failures can be expensive and potentially dangerous

- **Scheduled** – Do maintenance at a regular rate
  - Example: change car’s oil every 5,000 miles
  - Problem: unnecessary maintenance can be wasteful; may not eliminate all failures

- **Predictive** – Forecast when problems will arise
  - Example: text message from your vehicle that warns that fuel pump is about to die
  - Problem: difficult to make accurate forecasts; requires complex algorithms
Why perform prognostics and diagnostics?

- Example: faulty braking system leads to windmill disaster
  - https://youtu.be/-YJuFyjTM0s?t=39s
Why perform prognostics and diagnostics?

- Example: faulty braking system leads to windmill disaster
  - [https://youtu.be/-YJuFvjtM0s?t=39s](https://youtu.be/-YJuFvjtM0s?t=39s)
- Wind turbines cost millions of dollars
- Failures can be dangerous
- Maintenance also very expensive and dangerous
In the Automotive Industry

- **Heavy Equipment/Commercial Vehicles**
  - Many working on for several years
  - Meeting service agreements
  - Additional services to sell to customers

- **Passenger Vehicles**
  - Early programs already to market
  - Lot’s of buzz in the news
Techniques for Diagnostics and Prognostics

- Stochastic time-series modeling
  - AR (auto-regressive), ARMA (auto-regressive moving average), regression splines, Volterra series expansion

- Estimation and Controls
  - Kalman filters, extended Kalman filters, state-space models, transfer function models

- Machine Learning
  - Neural networks, nearest neighbors, decision trees

Focus of today’s talk.
Machine Learning

Machine learning uses **data** and produces a **program** to perform a **task**

**Task:** Human Activity Detection

### Standard Approach

- **Hand Written Program**
  - If $X_{\text{acc}} > 0.5$
    - then “SITTING”
  - If $Y_{\text{acc}} < 4$ and $Z_{\text{acc}} > 5$
    - then “STANDING”
  - ...

- **Formula or Equation**
  \[
  Y_{\text{activity}} = \beta_1 X_{\text{acc}} + \beta_2 Y_{\text{acc}} + \beta_3 Z_{\text{acc}} + \ldots
  \]

### Machine Learning Approach

- **Model:** Inputs $\rightarrow$ Outputs

\[
\text{model} = \langle \text{Machine Learning Algorithm} \rangle (\text{sensor_data, activity})
\]
Different Types of Learning

Machine Learning

Supervised Learning
- Develop predictive model based on both input and output data
- Classification
  - Classify if “ok” or “needs maintenance”
  - Classify driver “style”
- Regression
  - Predict time until failure

Unsupervised Learning
- Discover an internal representation from input data only
- Clustering
  - Find outliers in sensor data
  - Find clusters of operating ranges

Categories of Algorithms
Different Types of Learning

- **Supervised Learning**
  - Develop predictive model based on both input and output data
  - **Classification**
    - Support Vector Machines
    - Discriminant Analysis
  - **Regression**
    - Linear Regression
    - GLM
    - SVR, GPR
    - Ensemble Methods
    - Decision Trees
    - Neural Networks

- **Unsupervised Learning**
  - Discover an internal representation from input data only
  - **Clustering**
    - kMeans, kmedoids
    - Fuzzy C-Means
    - Hierarchical
    - Gaussian Mixture
    - Neural Networks
    - Hidden Markov Model

Machine Learning

Categories of Algorithms
Different Model Structures

**Decision Tree**

- \( X_1 < 4 \)
  - yes
  - \( X_2 > 9 \)
    - yes
      - Dog
    - no
  - no
    - \( X_2 > 1 \)
      - yes
        - Cat
      - no
        - Cat

**Support Vector Machine**

- \( y = mx + b \)
  - Points on the graph
    - \( O \)
    - \( \circ \)
“essentially, all models are wrong, but some are useful”
– George Box
Example: Classification

**Type of Learning**

- **Supervised Learning**
  - Develop predictive model based on both input and output data

- **Unsupervised Learning**
  - Discover an internal representation from input data only

**Categories of Algorithms**

- Classification
- Regression
- Clustering

**Objective:**
Train a classifier to predict how close to failure a component is.

**Data:**

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Engine Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outputs</td>
<td>Time to maintenance: urgent, short, medium, long</td>
</tr>
</tbody>
</table>
Case Study: Predictive Maintenance of Turbofan Engine

Sensor data from 100 engines of the same model

Scenario: Have failure data
- Performing scheduled maintenance
- Failures still occurring (maybe by design)
- Search records for when failures occurred and gather data preceding the failure events
- Can we predict how long until failures will occur?

Data provided by NASA PCoE
http://ti.arc.nasa.gov/tech/dash/pcoe/prognostic-data-repository/
### MATLAB: A Suite for Machine Learning

<table>
<thead>
<tr>
<th>Steps</th>
<th>Challenge</th>
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</thead>
<tbody>
<tr>
<td>Accessing, exploring and analyzing data</td>
<td>Data diversity</td>
</tr>
<tr>
<td>Preprocess data</td>
<td>Lack of domain tools</td>
</tr>
<tr>
<td>Train models</td>
<td>Time consuming</td>
</tr>
<tr>
<td>Assess model performance</td>
<td>Avoid pitfalls</td>
</tr>
<tr>
<td></td>
<td>Over Fitting, Speed-Accuracy-Complexity</td>
</tr>
<tr>
<td>Iterate</td>
<td></td>
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</table>
Machine Learning Workflow

**Train:** Iterate till you find the best model

**Predict:** Integrate trained models into applications
Integrate analytics with your enterprise systems

MATLAB Compiler and MATLAB Coder
Case Study: Human Activity Learning Using Mobile Phone Data

Data:
- 3-axial Accelerometer data
- 3-axial Gyroscope data
Learn More

- **Webinars:**
  - Predictive Maintenance with MATLAB: A Prognostics Case Study
  - Signal Processing and Machine Learning for Sensor Data Analytics

- **Web Pages:**
  - Machine Learning
  - Statistics and Machine Learning Toolbox
  - Neural Networks Toolbox
  - System Identification Toolbox
Key Takeaways

- MATLAB provides a wide variety of Machine Learning tools that are easy to get started with

- Deploy Prognostics and Diagnostics algorithms to where it makes sense, whether it’s on the vehicle or in IT infrastructure

- Work with us and we can help you get started applying these techniques