SETTING UP OF A
PROBABILISTIC NEURAL NETWORK
FOR SENSOR FAULT DETECTION
INCLUDING
OPERATION WITH COMPONENT FAULTS

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Setting Up Of A Probabilistic Neural Network For Sensor Fault Detection Including Operation With Component Faults

Definition of the diagnostic problem

Probabilistic Neural Network Architecture

PNN diagnostic ability
  - Effect of noise level and operating conditions
  - Minimum detectable sensor biases
  - Multiple sensor faults
  - Sensor fault detection in a faulty engine
  - Sensor fault detection in a deteriorating engine

Summary - Conclusions
Setting Up Of A Probabilistic Neural Network For Sensor Fault Detection Including Operation With Component Faults

**Definition of the diagnostic problem**

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**Summary - Conclusions**
Definition of the Diagnostic Problem

Determine if the readings from a number of instruments are correct or not

High-by-Pass ratio, partially mixed, turbofan engine used as a test case
Setting Up Of A Probabilistic Neural Network For Sensor Fault Detection Including Operation With Component Faults

Definition of the diagnostic problem

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Summary - Conclusions
Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Input layer: Deltas of the measurements

Δ(XNLP)  Δ(XNHP)  Δ(P13)  Δ(P3)  Δ(T3)  Δ(T5)  Δ(T13)

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Pattern Generation from Measurements

XNLP, XNHP, P13, P3, T3, T5, T13

Δ(Y) = (Y - Ynom) / Ynom

Pamb, P1, T1, WFE

Nominal values:
XNLP, XNHP, P13, P3, T3, T5, T13

EPM

Pattern

Δ(XNLP) Δ(XNHP) Δ(P13) Δ(P3) Δ(T3) Δ(T5) Δ(T13)

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Turbofan Engine Modeling

- **Quantities defining the operating Conditions:**
  - Ambient Pressure
  - Fuel consumption
  - Engine Inlet Conditions (pressure, temperature)

- **Fault Parameters:**
  - Flow factors along the engine
  - Efficiency factors along the engine
  - Exhaust area

- **Measured quantities:**
  - Shafts’ speed (low and high pressure)
  - Pressures and temperatures along the engine
Hidden layer: Training patterns

\( m \sim 11,000 \) nodes

Each node: A Noise-free pattern produced by simulation
**Output layer: Considered classes**

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**Example**

Fuel flow reading is faulty
Materializing the Network

Generation of the patterns

Network once trained, then tested

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Aspects Examined to Assess Diagnostic Potential

- Effect of Noise
- Diagnosis at different Operating Conditions
- Minimum detectable sensor biases
- Multiple Sensor Faults detection
- Simultaneous presence of Component Faults
- Drifting Deterioration of Fault Parameters

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Aspects Examined to Assess Diagnostic Potential

Have been considered for:

A. Patterns for training the network

B. Patterns for testing the network
Setting Up Of A Probabilistic Neural Network For Sensor Fault Detection Including Operation With Component Faults

- Definition of the diagnostic problem
- Probabilistic Neural Network Architecture

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Summary - Conclusions
Examples of Test Patterns

(a) Healthy engine, Healthy sensors

(b) Faulty engine, Healthy sensors

(c) Healthy engine, Faulty sensor (XNLP)

(d) Faulty engine, Faulty sensor (XNLP)

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
PNN behavior in the presence of Noise

How the diagnostic ability is affected by the presence of noise?

Noise ‘blurs’ the diagnosis

A simple filtering procedure ‘narrows’ the region of ineffective diagnosis
### Effect of Noise Level

#### Noisy Data

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- ● Not Diagnosed
- □ Diagnosed

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Diagnosis at different Operating Conditions

How the diagnostic ability is affected at different operating conditions?

Diagnostic ability unaffected for ‘neighboring’ operating conditions
## Effect of Operating Conditions

### Trained OP

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- **Not Diagnosed**
- **Diagnosed**
Minimum detectable sensor biases

Which are the minimum sensor biases that can be detected?

Biases greater than 0.4% - 0.8% are detected for all sensors

Bias Levels usually represent 2-4 times the considered noise levels
Minimum detectable sensor biases

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Multiple Sensor Faults detection

How, possibly, multiple sensor faults can be detected?

Faults in up to three different sensors are detected efficiently

Sensors of measurements for condition monitoring
Multiple sensor faults

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Multiple sensor faults: Diagnostic procedure

Initial Pattern

Diagnosis
P(P13) > 50%

Modified Pattern

Diagnosis
P(XNLP) > 50%

Diagnosis
P(Ok) > 50%
Sample result

Success rate for Multiple sensor faults

Correct diagnosis

Correct diagnosis

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Simultaneous presence of Component Faults

How the diagnostic ability is affected at the simultaneous presence of Component Faults?

Detectable biases are larger

Sensor Biases larger than ±1% are detectable for usual component faults
Sensor fault detection in a faulty engine

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Drifting Deterioration of Fault Parameters

How the diagnostic ability is affected in a deteriorated engine?

The general trend is that ±1% biases are detectable for deterioration levels of up to ±0.5% fault parameters deviation.
Sensor fault detection in a deteriorating engine

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Sensor fault detection in a deteriorating engine

Setting up of a Probabilistic neural Network for sensor fault detection including operation with component faults
Conclusions - Results

• Flexible and easy to build network

• Wide range of effective diagnosis

• Cases of Multiple sensor faults handled efficiently

• Robustness in the presence of component faults or deterioration

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