RUL Prediction for Cold Forming Production Tooling

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Resume of the presenter

- Current position
  - Postdoc at the Eindhoven University of Technology (The Netherlands)
- Previous positions
  - Postdoc at the Norwegian University of Science and Technology (Norway)
  - Scientific researcher at KU Leuven (Belgium)
  - Scientific researcher at Ghent University (Belgium)
- Research experience
  - Machine learning
  - Bioinformatics
  - Statistics

Outline

1. Introduction
2. Data collection and feature extraction
3. Cluster analysis

Purpose of the paper

- Contents of the paper
    - Work-in-progress contribution
    - Description of some results of the ▸ Prophesy project on predictive maintenance
- Goal of the Prophesy project
    - Collaboration with Jaguar Land Rover and Philips
    - Paper restricts to the Philips case
- Data set
    - Force-signals at different angles during the forming process of some metal part
- Specific purpose
    - Remaining useful lifetime (RUL) prediction
        - Cf. next slide
    - What is remaining number of die hits before breakdown?

Work-in-progress contribution

- Reason why work in progress
  - No times of failure are currently available for Philips use case
  - Consequently, only unlabelled data and no RUL prediction for predictive maintenance possible
  - Considered alternative: cluster analysis

Predictive maintenance

- Data-driven process of predicting when operational equipment may fail
- Idea is that maintenance should be performed as far in the future as possible
- Purpose: reducing maintenance costs
- Predicted output variable by predictive maintenance method: RUL
  - How long is the machine expected to continue to run without failure?

Description of the use case

Philips

- Development of rotary shavers, beard trimmers, hairdryers, epilators, vacuum cleaners, SENSEO coffeemakers, etc.
- Employs 2000 people
- Multiple production lines take care of cold forming metal parts
- Prophesy project is dedicated to a single production line

Tooling maintenance

- A production run for the tool maintenance is triggered by production because of:
  - Production run finished.
  - Pre-defined lifetime threshold reached.
  - Product quality issue or tool malfunction.

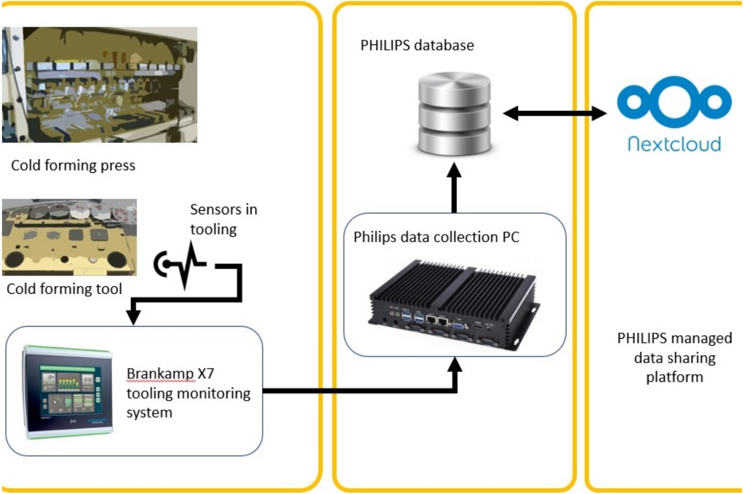

Figure: Global overview of the use case.

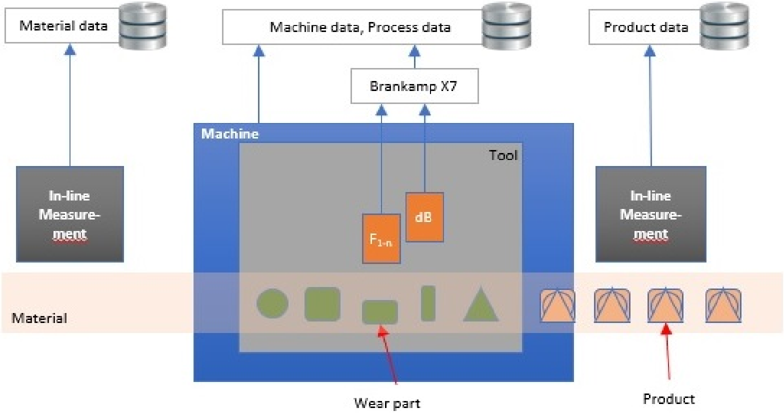

Figure: Some technical details of the use case.

Data set

- Force-signal as registered during the cold-forming operation
- During one stroke of the cold forming press, the cutting force is stored at 500 measurement points
    - Measured by a sensor manufactured by United Electric Controls
- These 500 measurement points correspond to force-signals at angles ranging from 50 degrees to 110 degrees in steps of 0.12 degrees
- At a normal production rate, 1 stroke is stored every 60 seconds
- 13 production runs are eligible to be used as training data

Feature extraction

- As there are 500 input variables, it is necessary to perform a dimensionality reduction
- Four features were extracted:
    1. Variable 1: the 90% percentile force at angle 71.72 degrees.
        - The 90% percentile is taken over time windows consisting of 251 time points
    2. Variable 2: the Area Under the Curve (AUC) of the forces between 70 and 75 degrees
    3. Variable 3: the 90% percentile force at 79 degrees
    4. Variable 4: the AUC of the forces between 78 and 80 degrees

Cluster analysis (1)

- Reminder: no failures present
- Alternative: unsupervised cluster analysis of the 13 production runs
- Cluster analysis is performed using k-means
  - Clustering is performed for each of the 4 feature variables
  - Optimal number of clusters is found to be 2, using cluster validation measures

Cluster analysis (2)

	Variable 1	Variable 2	Variable 3	Variable 4
Production run 1	1	1	1	1
Production run 2	1	1	1	1
Production run 3	1	1	1	1
Production run 4	1	1	1	1
Production run 5	1	1	2	2
Production run 6	1	1	2	2
Production run 7	1	1	2	2
Production run 8	1	1	2	2
Production run 9	2	2	2	2
Production run 10	2	1	2	2
Production run 11	2	1	2	2
Production run 12	2	1	2	2
Production run 13	2	1	2	2

Figure: Cluster index for each production run for each of the variables.

Cluster analysis (3)

- Previous table shows the following observations:
  - Production runs 1 to 4 are similar.
  - Production runs 5 to 8 are similar.
  - Production runs 9, 10, 11 and 13 are similar.
  - Production runs 10 to 13 are similar.
- Last two observations could also be rephrased as saying that production runs 9 to 13 are similar, with some dissimilarity between production runs 9 and 12.
- Are these results useful for RUL production?
  - Requires to analyze whether production runs 1 to 4, production runs 5 to 8, and production runs 9 to 13 share certain properties that might be related to the 'health' of the involved mechanical parts
  - If so, this knowledge can be used to predict the RUL.

Conclusion

- Work-in-progress contribution with a use case from a cold forming production tooling process
- Collaboration with Philips in the context of EU project Prophesy
- Purpose of the project is to predict the remaining useful lifetime of certain tools that come with high maintenance costs
- Currently no failure observations available in given data set
- Unsupervised cluster analysis shows that production runs can be grouped
- If different clusters can be linked to different properties related to remaining lifetime, this can be used to predict RUL in a later stage