On the Application of Machine Learning Techniques in Condition Monitoring Systems of Complex Machines

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Agenda

- Introduction
- Condition monitoring system – approach
- Interpretation of the signals – example
- Machine learning based analysis
- Software package for condition monitoring
- Further development

Introduction

- By knowing the exact condition state of a product, it is possible to:
  - Improve the maintenance (and reliability)
  - Increase the operability of the system (better prediction of failures based on improved understanding of the product)
  - Increase the satisfaction of the customer (higher availability of the product)
- Obviously, in case of safety critical systems, a precise condition state leads to increase of the system safety
- Development of new product market possibilities – pay per X

Condition monitoring system – introduction

1. Collection of machine data and information → 2. Interpretation of signals → 3. Establishment of the training matrix → 4. Machine learning based analysis → 5. Interpretation of the final results

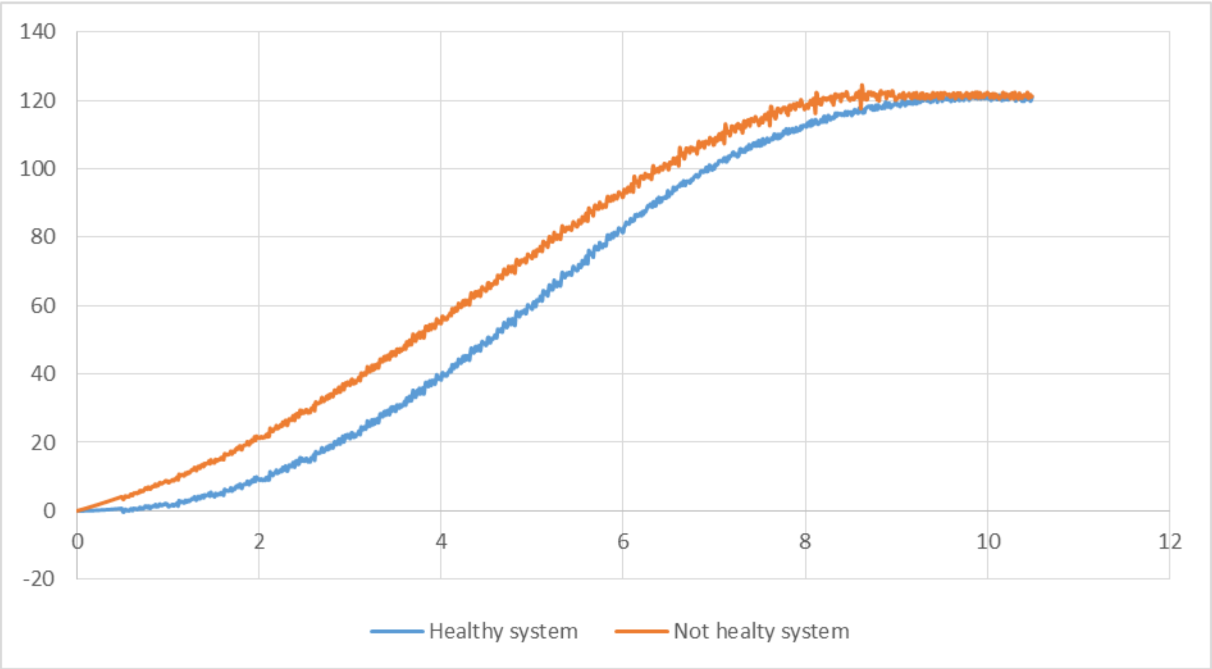
- The data itself can be extracted from the following data sources:
  - Product information in form of a constant data
  - Cumulative data as a single variable
  - Signals representing the change of a variable over time – sensor data
- Data treatment → NA values, missing values, outliers etc.
- Modell fit (incl. model preparation for the prognosis purposes)
- Numerical mathematics (machine learning) → various algorithms (e.g. C4.5, NNge, Neural Networks)

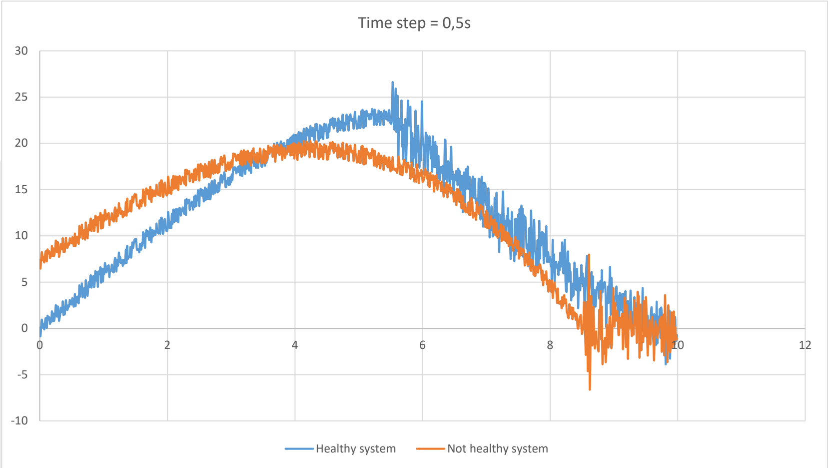
Condition monitoring system – introduction

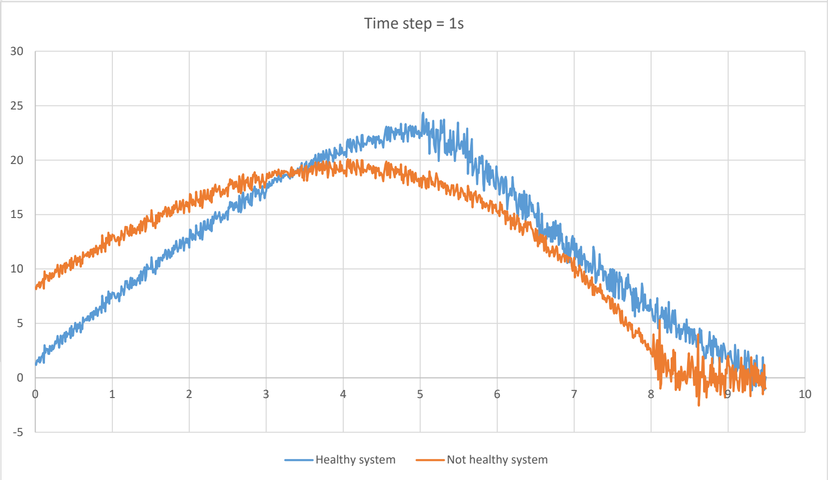
- Data interpretation:
  - Standardized statistical and mathematical methods for the analysis of signals like fast Fourier transform (FFT), time series analysis, descriptive statistics (mean, median, dispersion, variance), trend analysis and many more
  - Specified analysis of certain signals in combination with the specific knowledge of a given product like e.g. maximum speed or maximum acceleration of a car derived from the velocity signal
- Possibility of the treatment of unlabeled data → unsupervised learning
- Possibility of integration od additional data sources (e.g. interpretation of images)
- Visualization of final results

Interpretation of the signals - example

Calculation of the derivative of the signal based on the difference scheme (forward, backward, central)





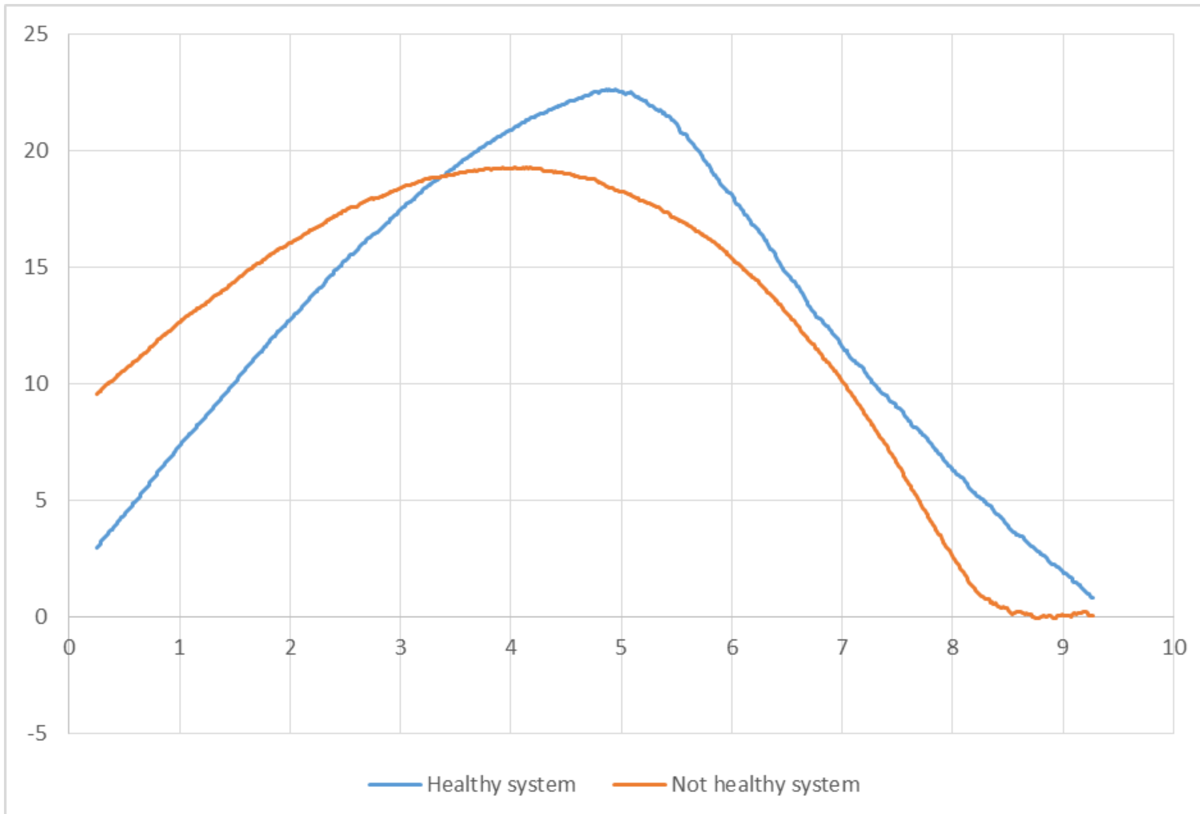


$$N_{\mathrm{forward}} = \frac{f(x+h) - f(x)}{h} \qquad N_{backward} = \frac{f(x) - f(x-h)}{h} \qquad N_{\mathrm{central}} = \frac{f(x+h) - f(x-h)}{2h}$$

Interpretation of the signals - example

The differentiation curve has to be smoothened first in order to reach explicit attributes for the description of the shift. For the smoothing of the curve, the moving average can be applied:

$$\bar{p}_S(t) = \frac{1}{n}\sum_{i=0}^{n-1} p(t-i)$$



Machine learning – state of the art

- **Supervised learning**: The underlying connection between input data and the upfront known target variable is established using training data
- **Unsupervised learning**: Used on unlabeled datasets with no knowledge about the required target variables. Hidden structures within the data are revealed
- **Reinforcement learning**: A sequence of actions gets explored by an intelligent agent that either rewards or punishes certain behavior. The aim is to maximize the cumulative gained reward
- The **C4.5** algorithm is a decision tree classifier that belongs to the class of supervised learning algorithms

$$I(S) = -\log_2\left(\frac{freq(C_j,S)}{|S|}\right)$$

$$Info(S) = -\sum_{j=1}^{k}\frac{freq(C_j,S)}{|S|}\times\log_2\left(\frac{freq(C_j,S)}{|S|}\right)$$

$$info_x(TT) = \sum_{i=1}^{n}\frac{|TT_i|}{|TT|}\times info(TT_i)$$

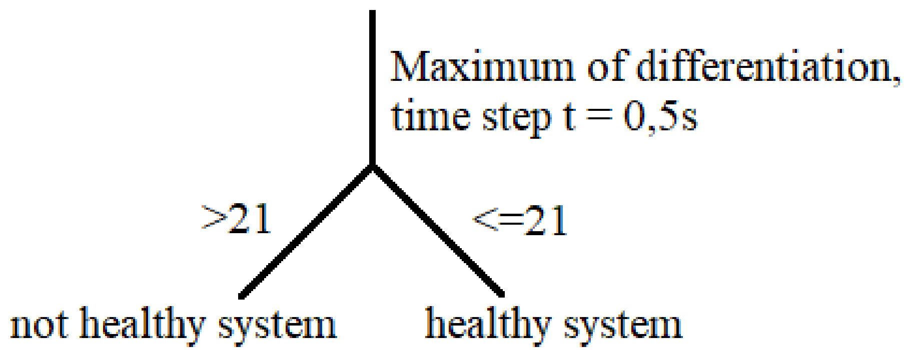
$$gain(X) = info(TT) - info_x(TT)$$

Machine learning – example

Training data established with the discussed example:

Max differentiate t=0.5s	Max differentiate t=1s	t_max of max diff t=0.5s	t_max of max diff t=1s	Tagret variable
19,37002604	19,28925506	4,13	4,03	Healthy system
23,01009687	22,65621314	5,36	4,89	Not healthy system

A typical result of the machine learning analysis in form of a decision tree and based on the discussed example performed with the C4.5 algorithm



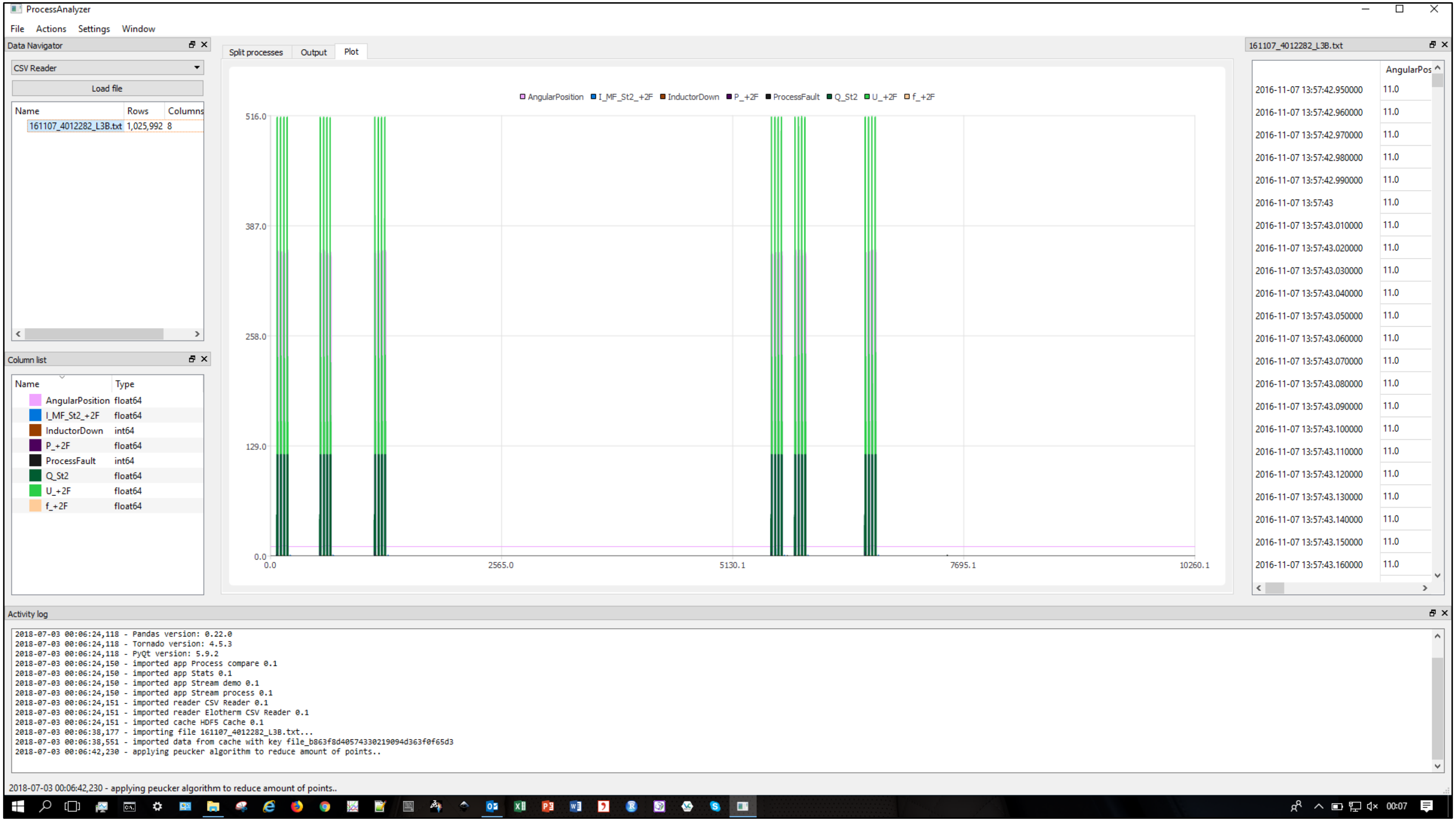
Software package for condition monitoring

- Data import / export and data manipulation:
  - Handling of various data formats (Excel, .csv, hdf5, MySQL, logger-files)
- Data manipulation:
  - Handling of NA-Values, proper identification of data types, manual treatment of data (with given formulas), resampling, unit conversion
- Visualisation of data (test series):
  - Handling of big-data with resampling (e.g. based on Peucker-algorithm)
- Splitting of time series into separate processes based on given rules:
  - Out of signals, the processes are extrapolated for the further statistical comparison

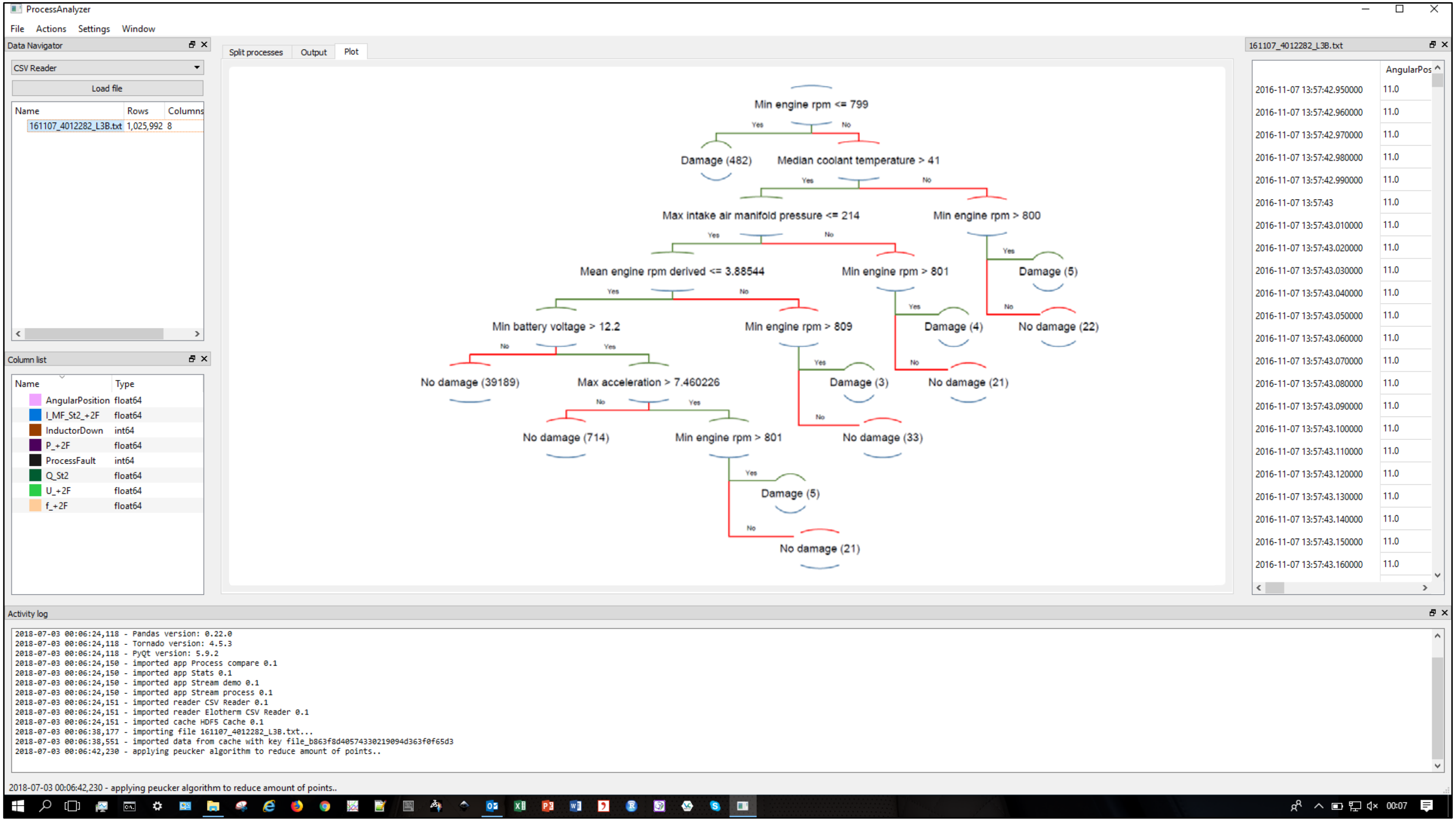
Software package for condition monitoring

- Determination of statistical values:
  - E.g. mean, median, quantiles, fast Fourier transform, rainflow counts
- Statistical tests:
  - Hypothesis test (e.g. Levene, F-/t-, Mann–Whitney U), trend analysis, curve fitting
- Detection of anomalies in the data sets (processes)
  - Based on machine learning algorithms (neuronal networks, inductive learning)
- Python based solution (various packages included: e.g. scipy, numpy, bokeh, pandas)

Software package for condition monitoring



Under development



Thank you for the attention!

Questions?