Prognostics Performance Evaluation

Abhinav Saxena[1], Jose Celaya[1], Bhaskar Saha[2], Sankalita Saha[2], Kai Goebel[3]
[1]Stinger Ghaffarian Technologies, Inc., [2]Mission Critical Technologies, Inc., [3]NASA ARC
Prognostics Center of Excellence, NASA Ames Research Center CA

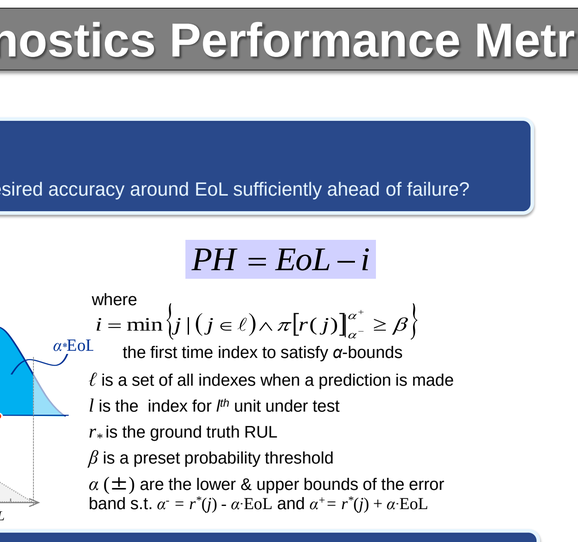
Objective

- Develop standard procedures and metrics to evaluate and compare performance of prognostic algorithms
- Develop a taxonomy/framework to define and describe a prognostics problem in a standardized manner

Motivation

- Performance evaluation methods customized to prognostics do not exist
- Researchers have loosely used ideas from diagnostics and other domains
- Prognostics performance evaluation is an "*acausal*" problem
  - Requires inputs from a future event, i.e. End-of-Life (EoL)
  - Classical methods are based on performance evaluation of casual systems, e.g. diagnostics
  - A confusion exists between offline and online performance evaluation
- A standard methodology will help compare different approaches in a consistent manner
- A standardized performance evaluation will help in performance requirement specification

Approach

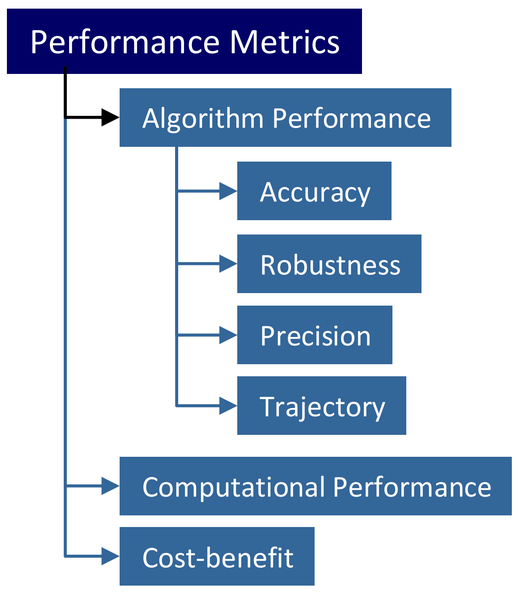


Shortcomings of Traditional Methods

- Traditional metrics do not encapsulate how predictions improve over time
  - In general predictions should improve as more data becomes available, but there is no provision to observe prediction evolution in time
- Prediction errors spaced in time should not be averaged as in diagnostic applications
  - Predictions made at different times are based on different amount of information
- Traditional metrics do not address the notion of performance relative to a reference point in time (t_λ)
  - Prognostics is time critical, a very accurate but late prediction may be useless as compared to somewhat approximate but an early prediction
  - Predictions should get more accurate as EoL approaches, so errors should be penalized more as time passes by
  - The reference point of interest (t_λ) may be chosen based on logistics constraints, risk absorbing capacity, rate of change of a dynamical system, etc. therefore, this calls for a comprehensive picture of performance spaced in time.

Prognostics Performance Metrics

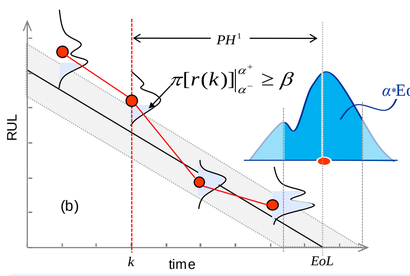
Metrics Classification



- A thorough survey was conducted to collect and classify performance metrics being used in a variety of domains like aerospace, finance, medicine, weather, etc.

I. Prognostic Horizon

- Does the algorithm predict within desired accuracy around EoL sufficiently ahead of failure?



$$PH = EoL - i$$

where

$i = \min\left\{ j \mid (j \in \ell) \wedge \pi[r(j)]_{\alpha^-}^{\alpha^+} \geq \beta \right\}$ the first time index to satisfy α-bounds

ℓ is a set of all indexes when a prediction is made

l is the index for l^{th} unit under test

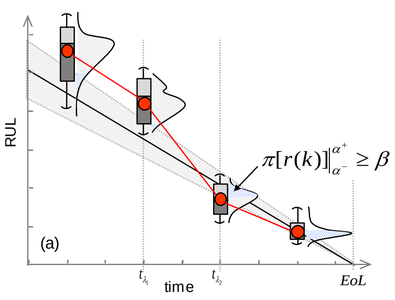
r_* is the ground truth RUL

β is a preset probability threshold

α (±) are the lower & upper bounds of the error band s.t. $\alpha^- = r^*(j) - \alpha \cdot EoL$ and $\alpha^+ = r^*(j) + \alpha \cdot EoL$

II. α-λ Performance

- Does the algorithm stay within desired performance levels relative to RUL at a given time?



Evaluate whether the following condition is met

$$\pi[r(t_\lambda)]_{\alpha^-}^{\alpha^+} \geq \beta$$

where

π is total probability mass of RUL pdf within α-bounds

t_λ is time window modifier s.t. $t_\lambda = t_P + \lambda(EoL - t_P)$

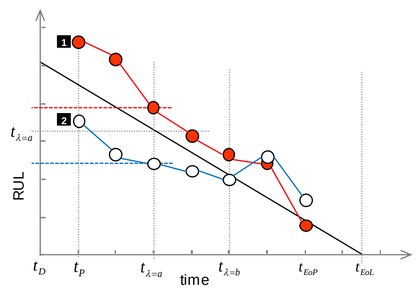
r_* is the ground truth RUL

β is a preset probability threshold

α (±) are the lower & upper bounds of the error band s.t. $\alpha^- = r^*(\lambda)(1-\alpha)$ and $\alpha^+ = r^*(\lambda)(1+\alpha)$

III. Relative Accuracy

- Quantify how accurate an algorithm is at a given time relative it's distance from EoL



$$RA_\lambda = 1 - \left| \frac{r_*(t_\lambda) - r_*^l(t_\lambda)}{r_*(t_\lambda)} \right|$$

where

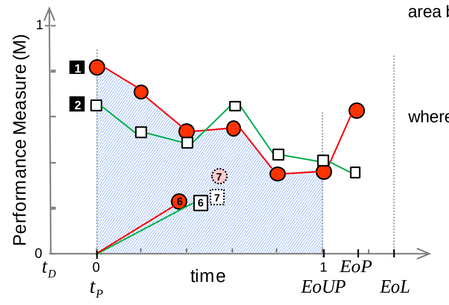
π is total probability mass of RUL pdf within α-bounds

t_λ is time window modifier s.t. $t_\lambda = t_P + \lambda(EoL - t_P)$

l is the index for l^{th} unit under test

IV. Convergence

- If the performance converges (satisfies above criteria), quantify how fast does it converge?



It can be shown that the magnitude of center of mass for the area below prediction trajectory represents convergence

$$C_M = \sqrt{(x_c - t_P)^2 + y_c^2}$$

where

$$x_c = \frac{\frac{1}{2}\sum_{i=P}^{EoP}(t_{i+1}^2 - t_i^2)M(i)}{\sum_{i=P}^{EoP}(t_{i+1} - t_i)M(i)}, \text{ and}$$

$$y_c = \frac{\frac{1}{2}\sum_{i=P}^{EoP}(t_{i+1} - t_i)M(i)^2}{\sum_{i=P}^{EoP}(t_{i+1} - t_i)M(i)}.$$

Performance Evaluation Tool

- Performance Evaluation helps researchers develop and improve their algorithms and methods
- This also helps in defining the requirements for prognostics

- A software tool has been developed to allow researchers evaluate their algorithms
- Tool is freely available for download from DaSHLink
- Search on the web "DashLink + Performance Evaluator"