Robust Sequential Probability Ratio Test for The Detection of Acoustic Emission Events

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Nowadays Acoustic Emission (AE) testing is a current non-destructive testing method for finding leakages and cracks in the material of pressure vessels. There are several methods for detecting events (anything that is not background noise) in those scenarios, such as classical signal threshold, spectral, or artificial intelligence-based methods. One technique widely used is a combination of Autoregression Filtering and the Sequential Probability Ratio Test (AR+SPRT) [3]. This is one of the distribution-based methods [4], and the subject of this paper.

Autoregressive filtering of the time signal is used to eliminate dependence in the time series. This turns the time signal into a set of independent, identically distributed random variables $(z_1, z_2, \dots, z_i)$, ready for the SPRT hypothesis testing procedure to be performed on it. The null hypothesis of the procedure, H_0, is that there is no event. The alternative hypothesis, H_1, is that an event is measured. The log likelihood ratio test statistic in step i of the procedure is the

$$\lambda_i = \ln\left(\frac{\prod_{l=1}^{i} f\left(z_l \mid H_1\right)}{\prod_{l=1}^{i} f\left(z_l \mid H_0\right)}\right),$$

where f is the density function of the distribution under the given condition [1]. Wald's original idea [5] of the uneventful time signal distribution has an expected value of 0 and σ_0^2 standard deviation normal distribution (P_0), while the event time signal distribution has an expected value of 0 and σ_1^2 standard deviation normal distribution (P_1).

In this talk, we would like to present an event detection method we have introduced, using together autoregressive filtering and a robust version of the sequential probability ratio test. A statistical procedure is said to be robust if its performance is insensitive to small deviations from the idealized theoretical model. In our case, this is necessary, because the time signal obtained as a result of AR filtering has only a near-normal distribution. We worked with the distribution families introduced by Huber [2]. Let $\mathcal{K}$ be the total set of probability measures in the real numbers space, and $0 < \varepsilon_0 < \varepsilon_1 < 1$ are given real numbers. Let

$$\mathcal{P}_0 = \left\{Q \mid Q = \left(1-\varepsilon_0\right) P_0 + \varepsilon_0 H_0, H_0 \epsilon \mathcal{K}\right\}, \text{ and}$$
$$\mathcal{P}_1 = \left\{Q \mid Q = \left(1-\varepsilon_1\right) P_1 + \varepsilon_1 H_1, H_1 \epsilon \mathcal{K}\right\}$$

formalise the small deviations from the idealised (P_0, P_1) models in the original null hypothesis and the alternative hypothesis.

We performed a simulation study comparing the performance of the classic (Wald) and the robust (Huber) SPRT on a time signal that included "bad" observations (deviations from the baseline distributions). The robust SPRT is less sensitive to these "bad" observations, although it is slower in deciding hypotheses.

We have tested the event detection methods also on a real measured time signal, coming from a Gleeble 3800 thermo-mechanical physical simulator. The results are shown in Figure 1. The upper plot shows Huber's function λ applied to a 0.1 second

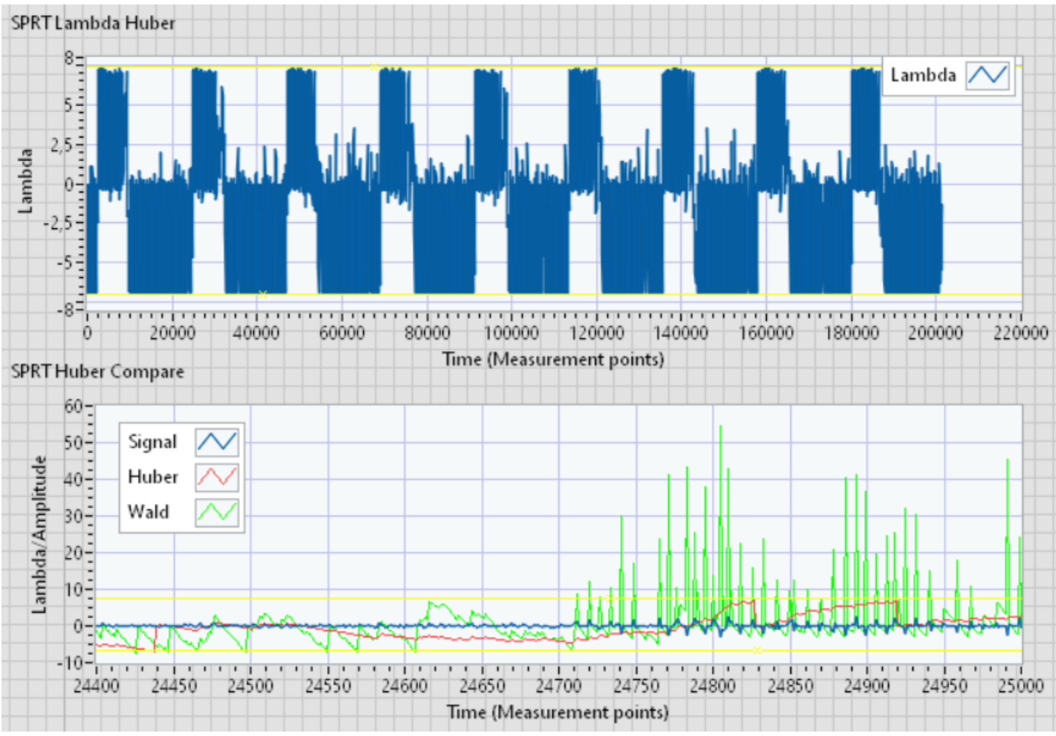

Figure 1: Robust SPRT on the measured time signal.

time signal. In the bottom plot, we zoomed in the start of the second event from the upper plot, where the blue line is the residual of the AR(14) filtered time signal, the red line is Huber's function λ, and the green line is Wald's SPRT function λ. The point of Huber's generalisation was to take out the big jumps, and we can confirm, based on the real measurement data, that is was successful. However, adding Huber's restrictions led to delayed decision making.

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